

# **DAMIC at SNOLAB**

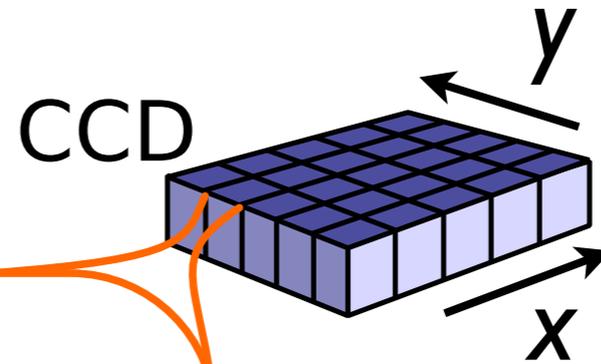
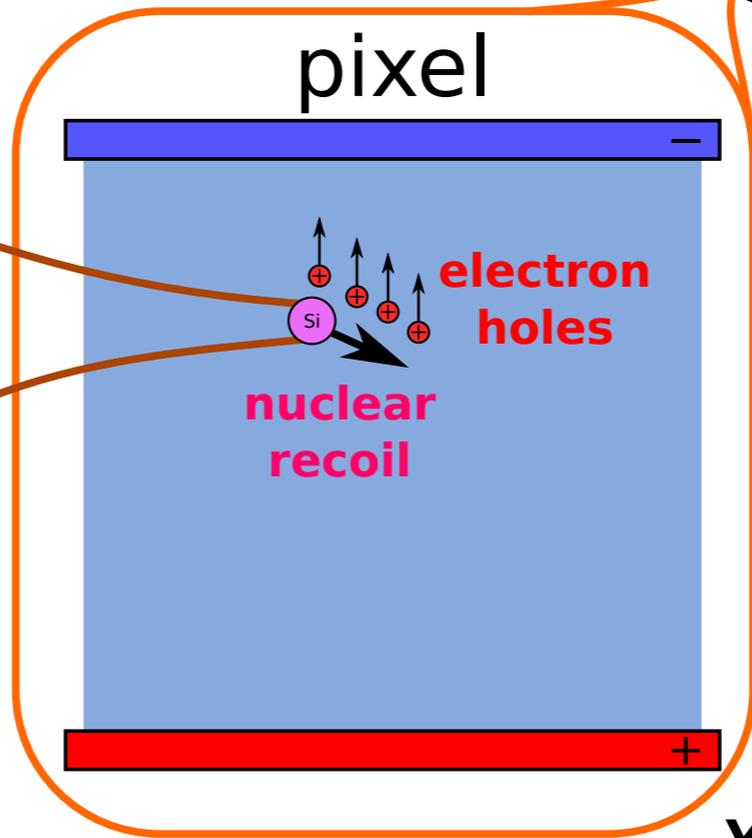
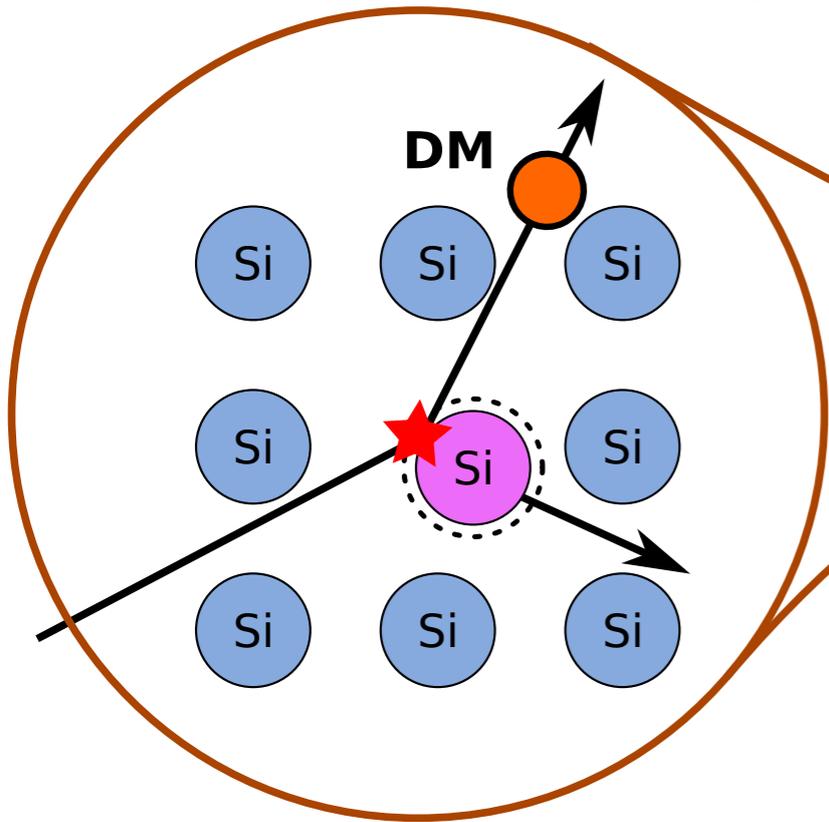
Alvaro E. Chavarria,  
KICP at U Chicago  
for the DAMIC Collaboration

# Overview

- Use the Si in a CCD bulk as a WIMP target.
- Very good ionization detector.
- Low electronic read out noise ( $\sim 2$  e<sup>-</sup> RMS) allows for a low energy threshold.
- Position reconstruction.
- Good characterization and estimation of backgrounds.
- Aim to build a detector large enough to explore CDMS-Si result ( $\sim 0.1$  kg) in a  $\sim 1$  year timescale.
- Fermilab, U Chicago, U Zurich, Michigan, UNAM, FIUNA, CAB.

# Detector

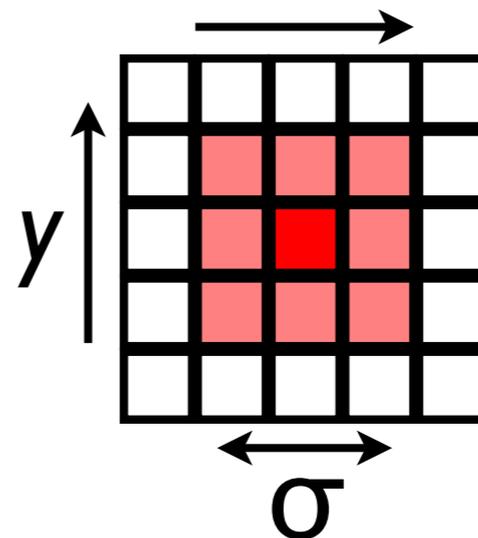
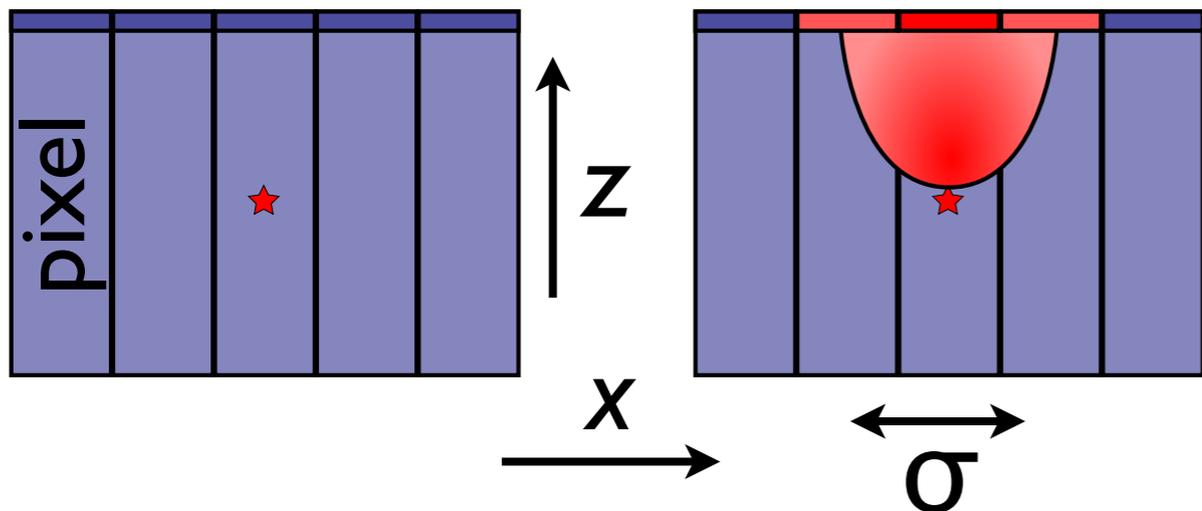
coherent elastic scattering



Charged particles produce ionization in CCD bulk

3.62 eV for e-h pair

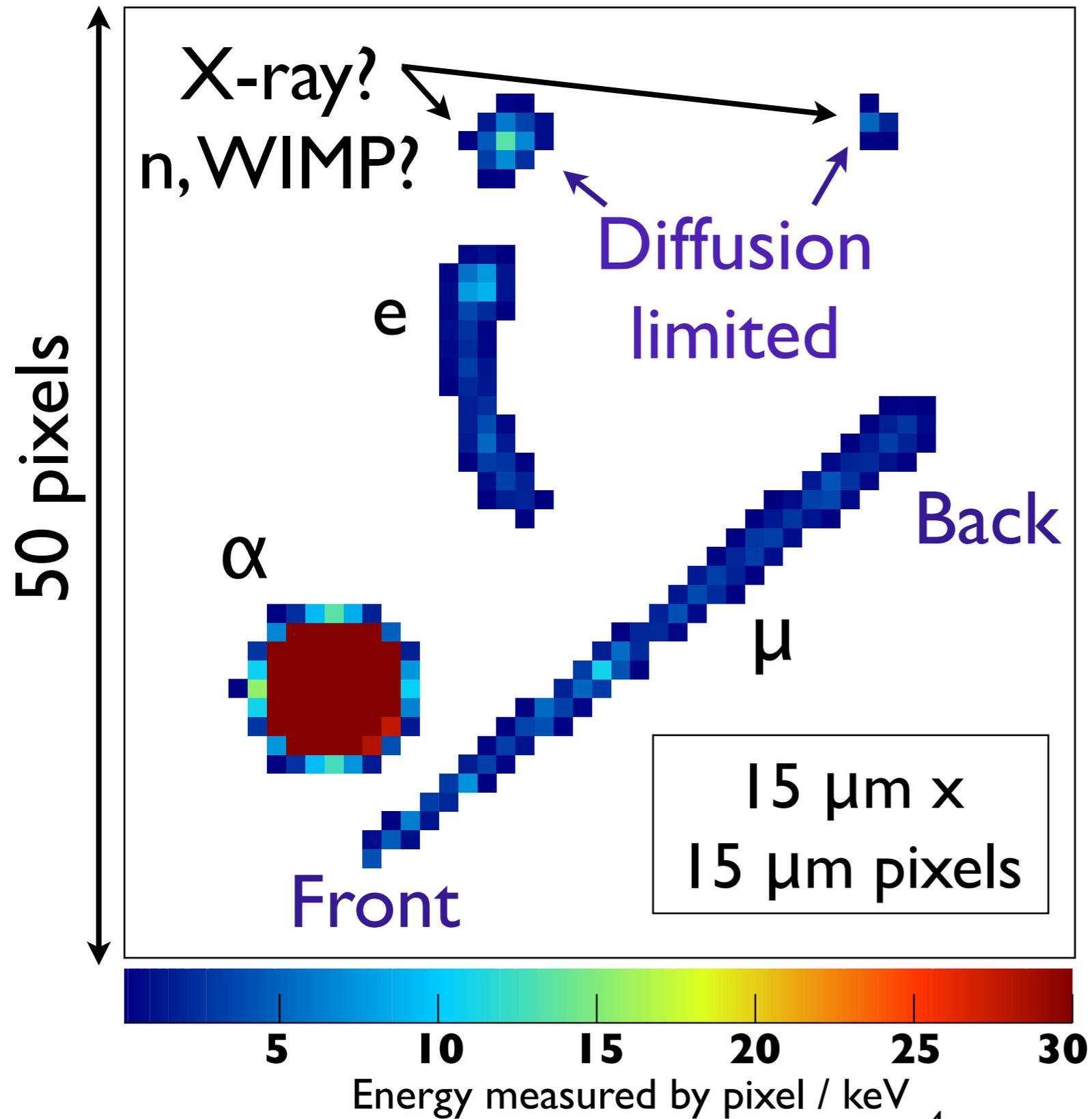
Charge drifted up and held at gates



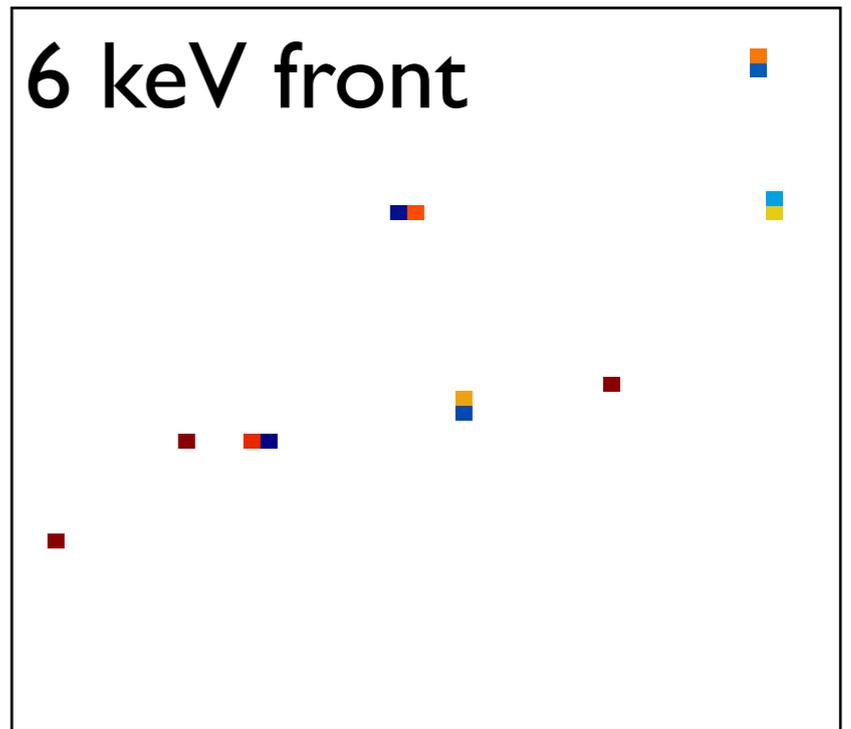
Charge collect by each pixel on CCD plane is read out

$\sim 2 e^-$  RMS read-out noise

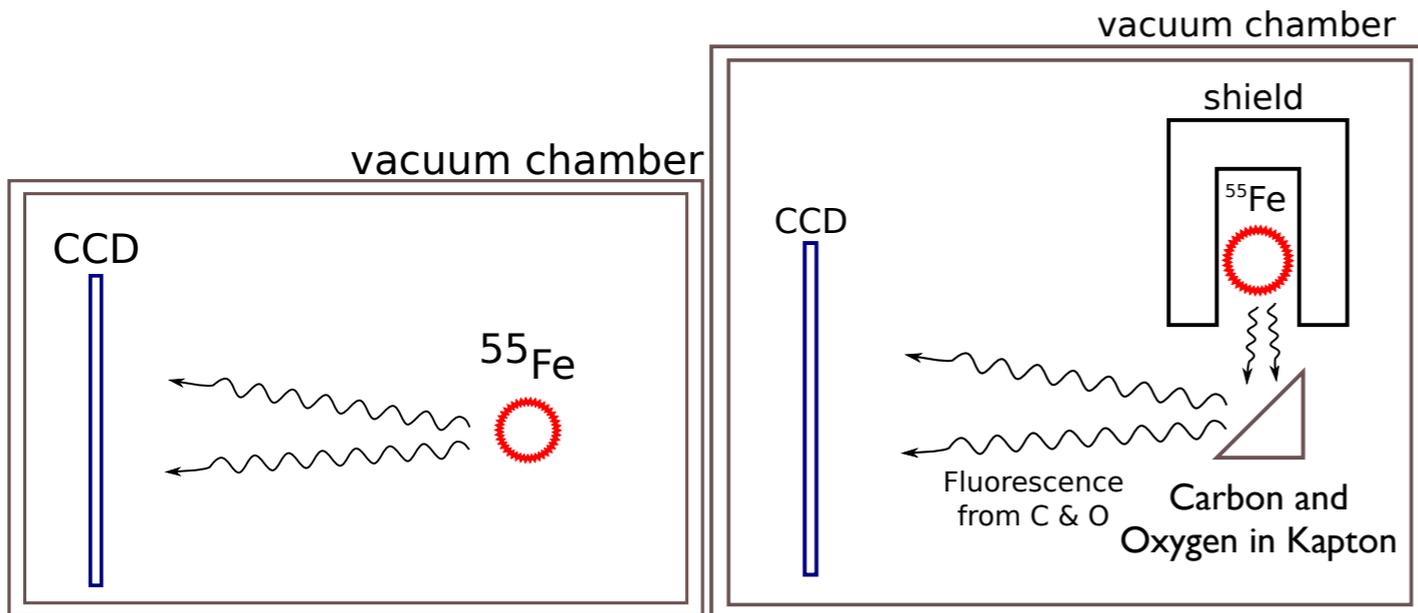
# Particle tracks



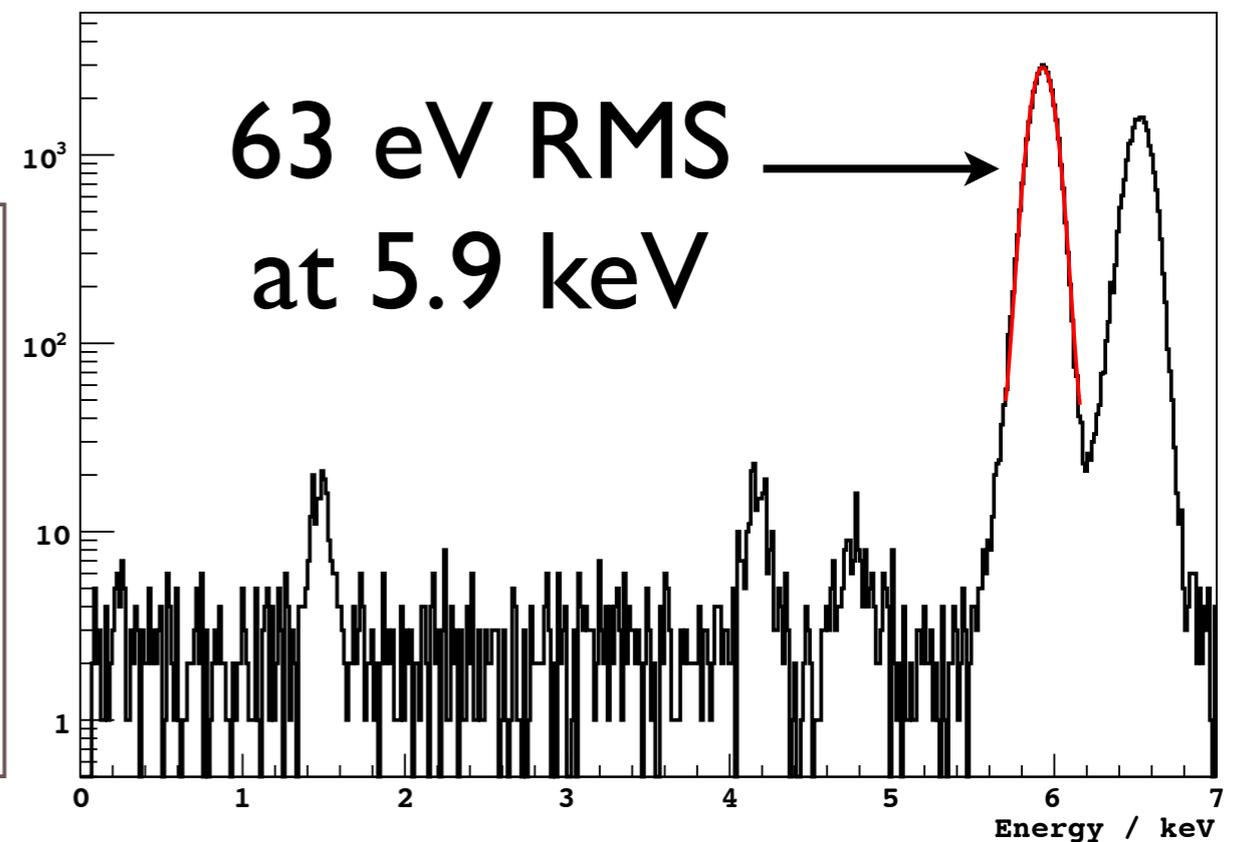
## Diffusion limited



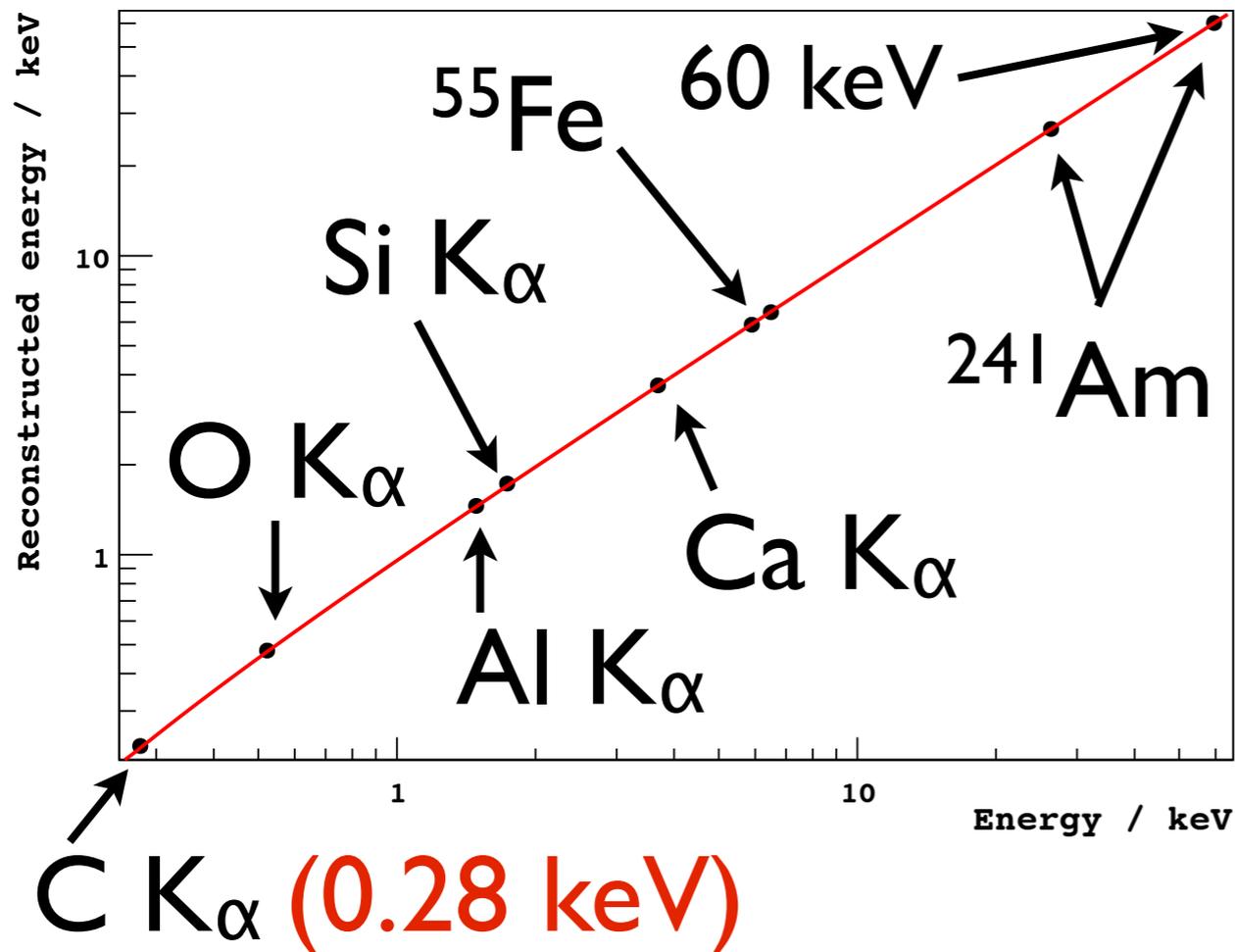
# E response



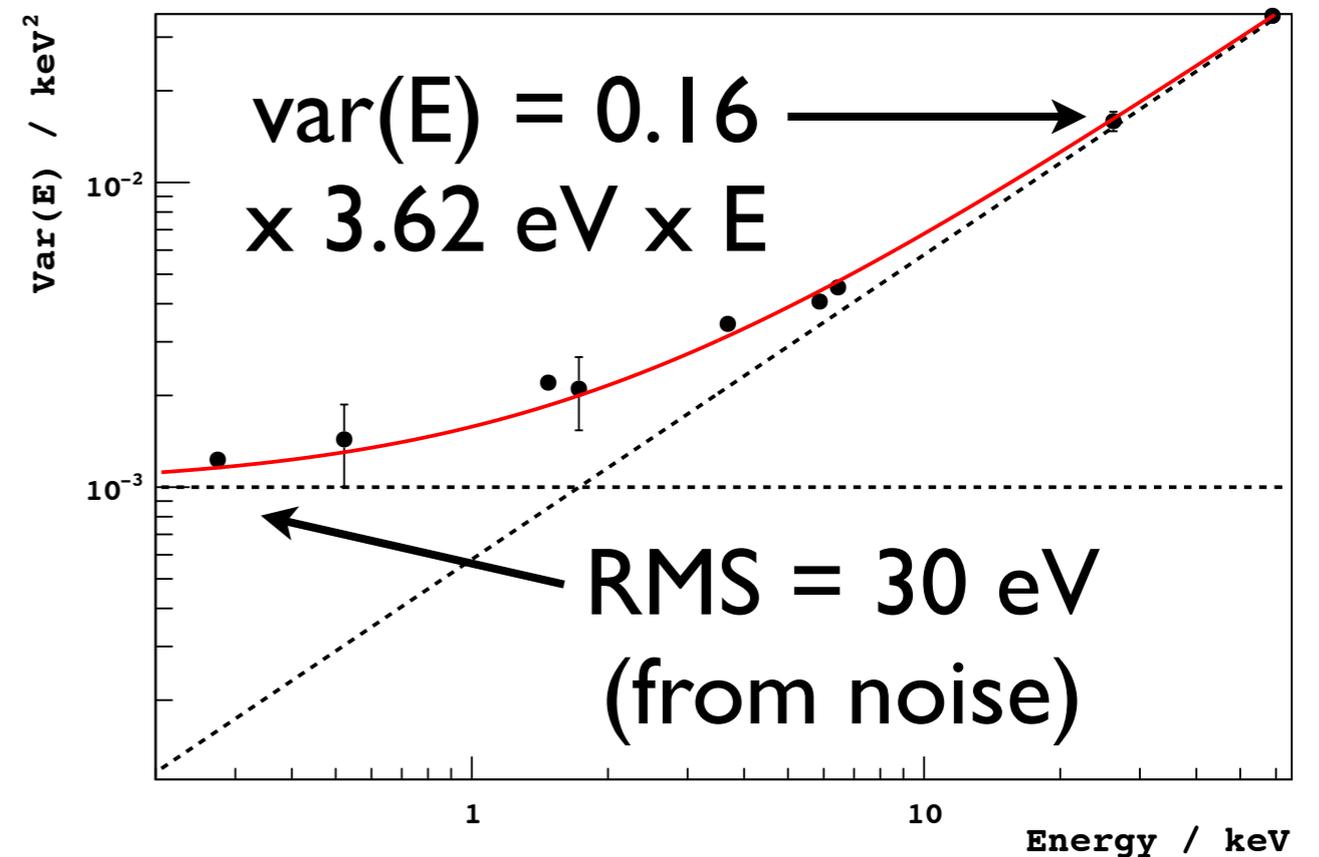
Spectrum from  $^{55}\text{Fe}$  source from back



Calibration data to X-ray lines



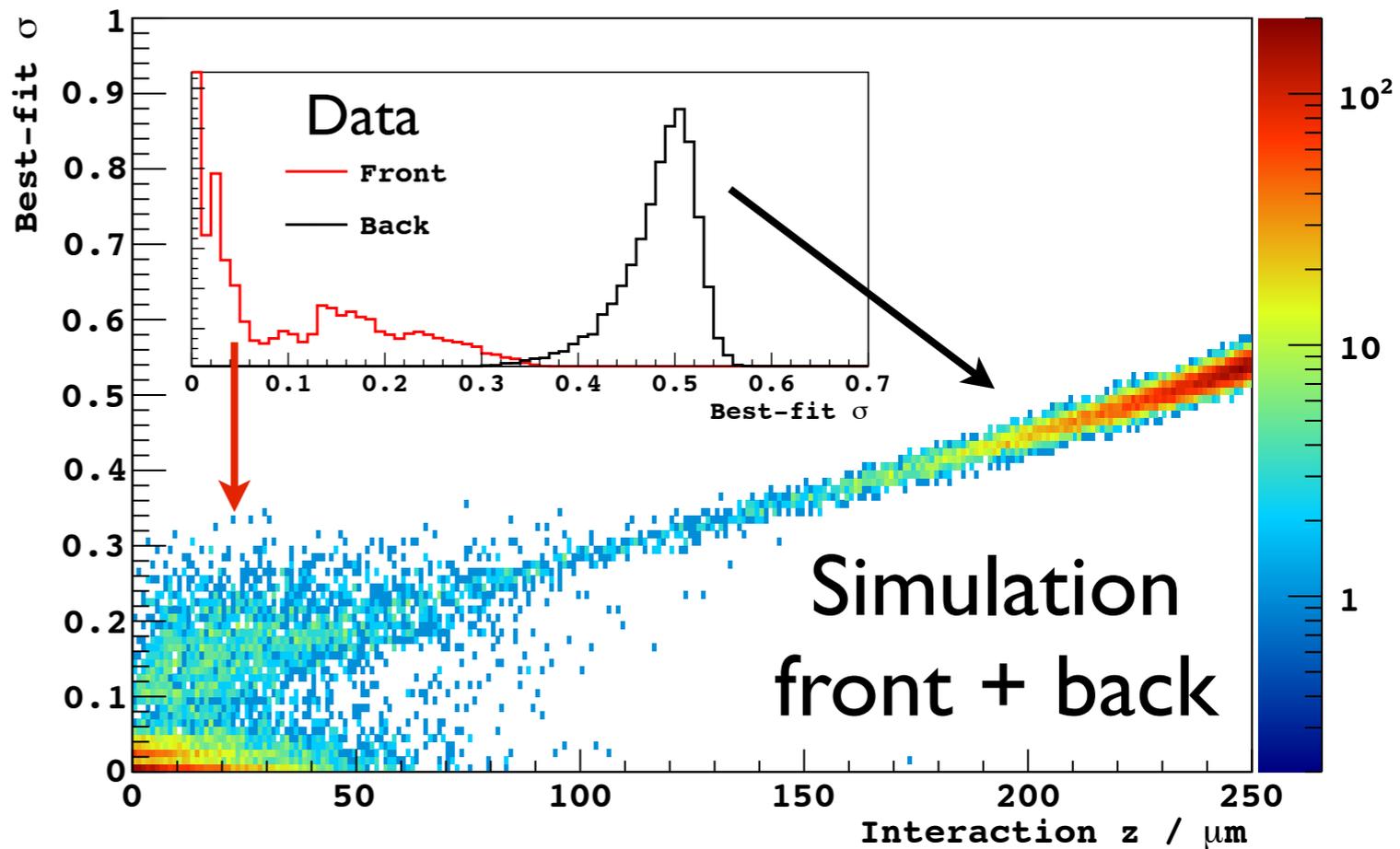
Energy resolution (back illumination)



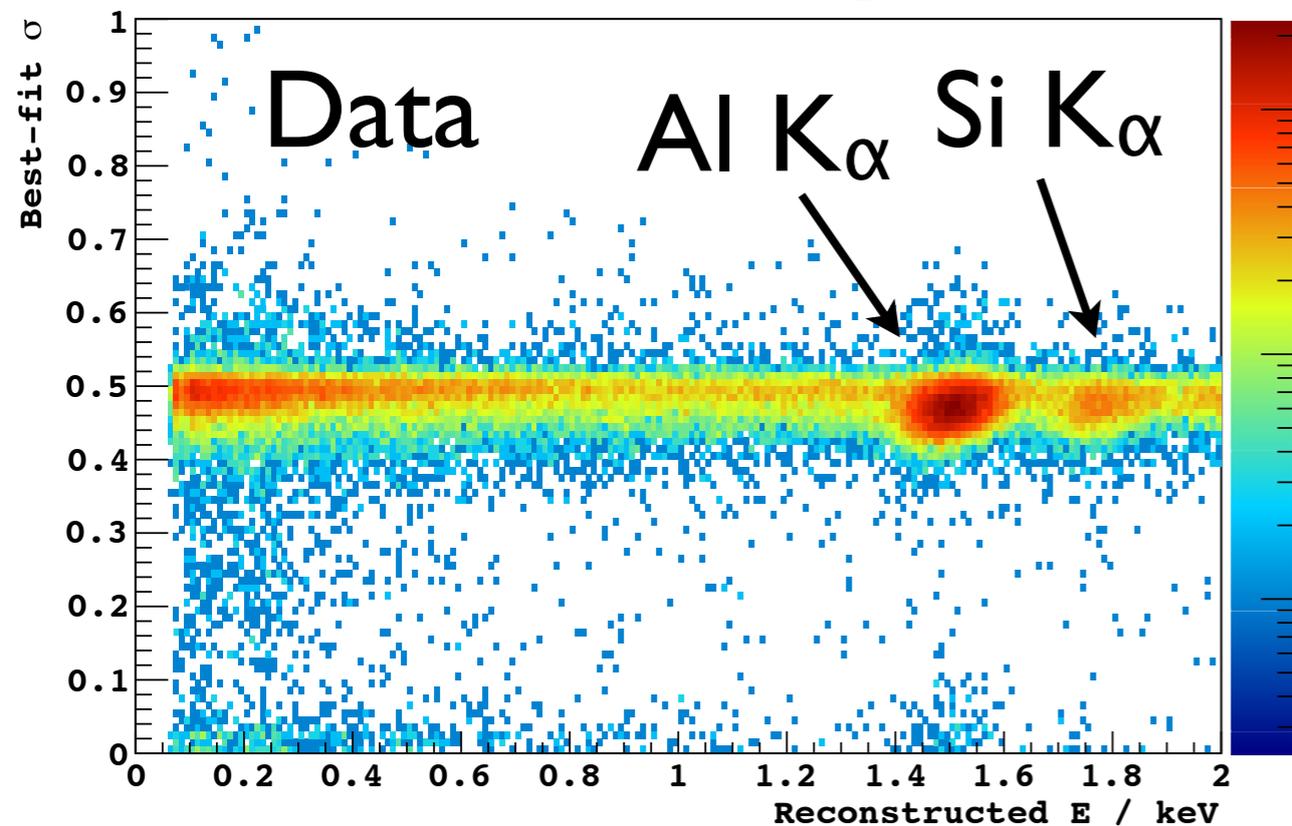
# Diffusion

Fit to the radial spread of the cluster allows us to estimate its position in  $z$  within the CCD bulk

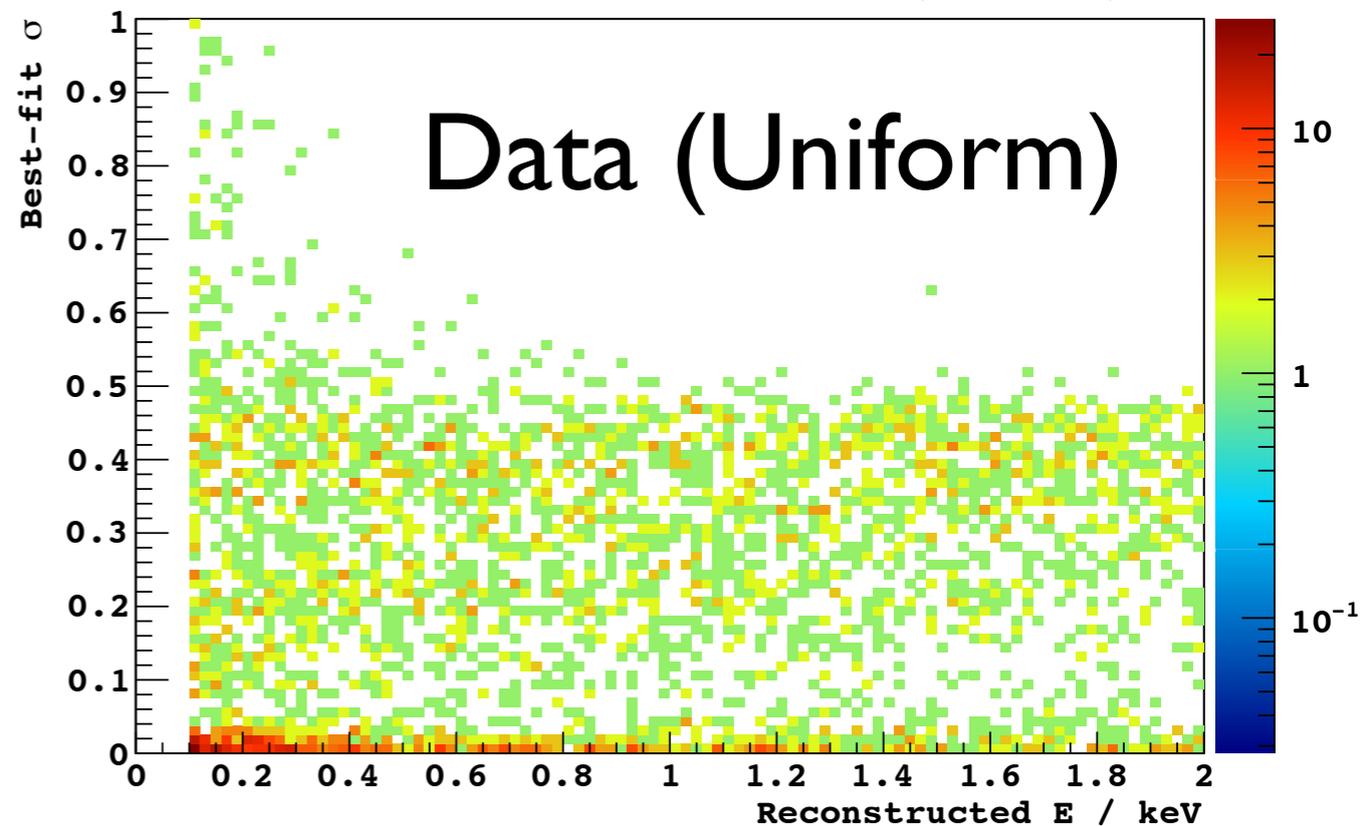
$^{55}\text{Fe}$  (6 keV X-ray) front + back



Low E fluorescence X-rays from back



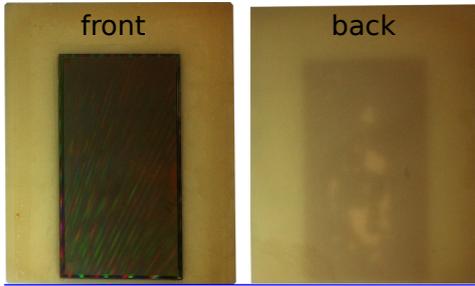
Events from  $^{252}\text{Cf}$  source (uniform)



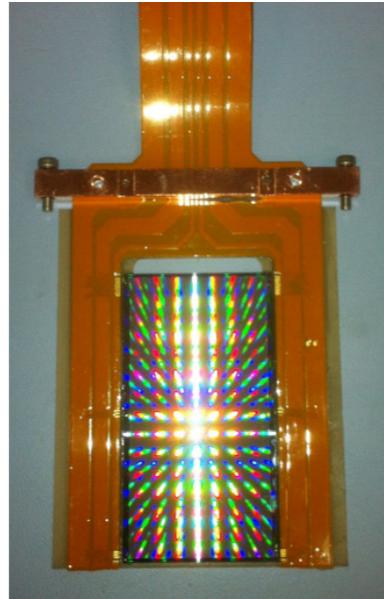
# Setup at SNOLAB

Two supports:

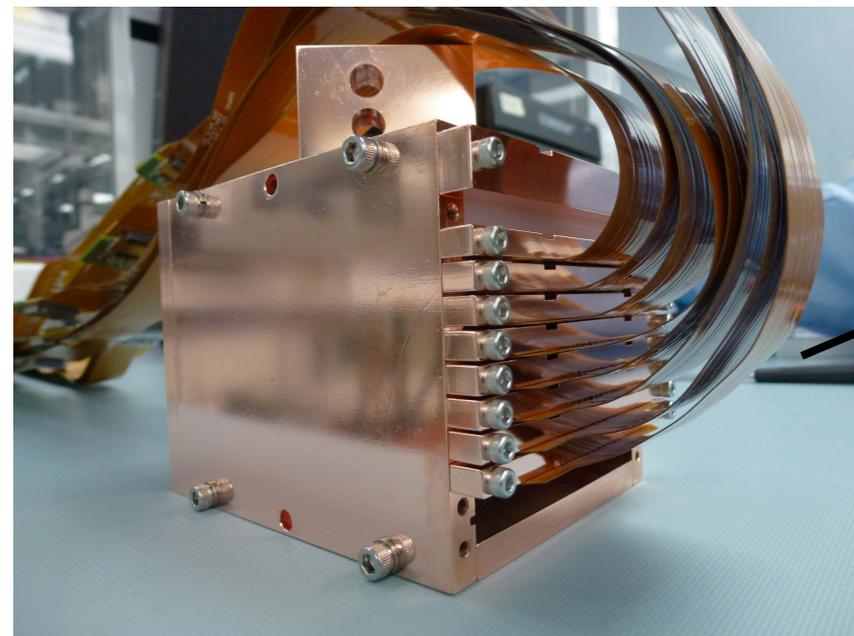
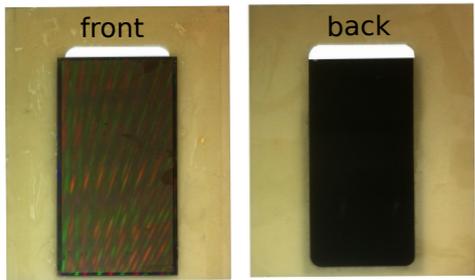
Full AIN



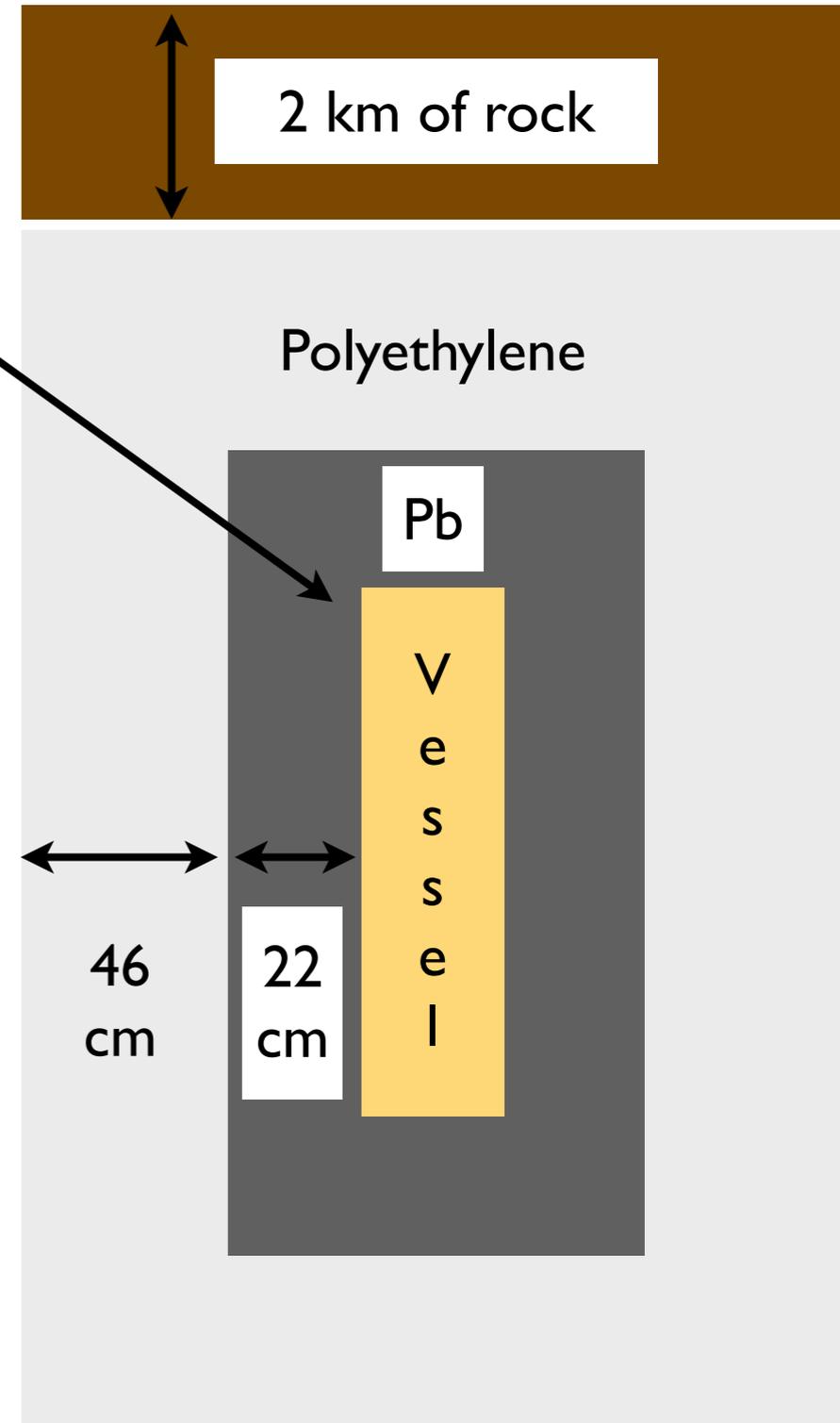
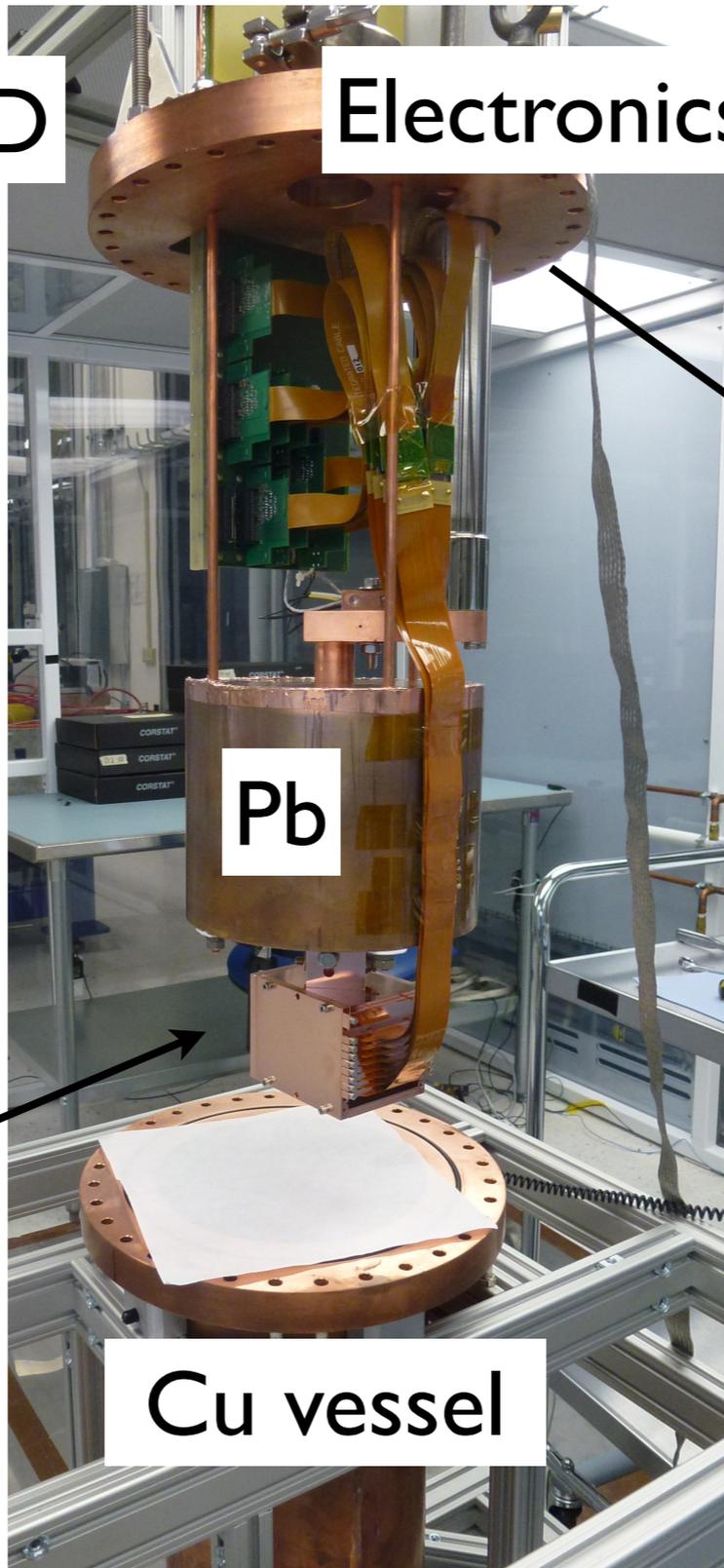
Wired CCD



Frame AIN

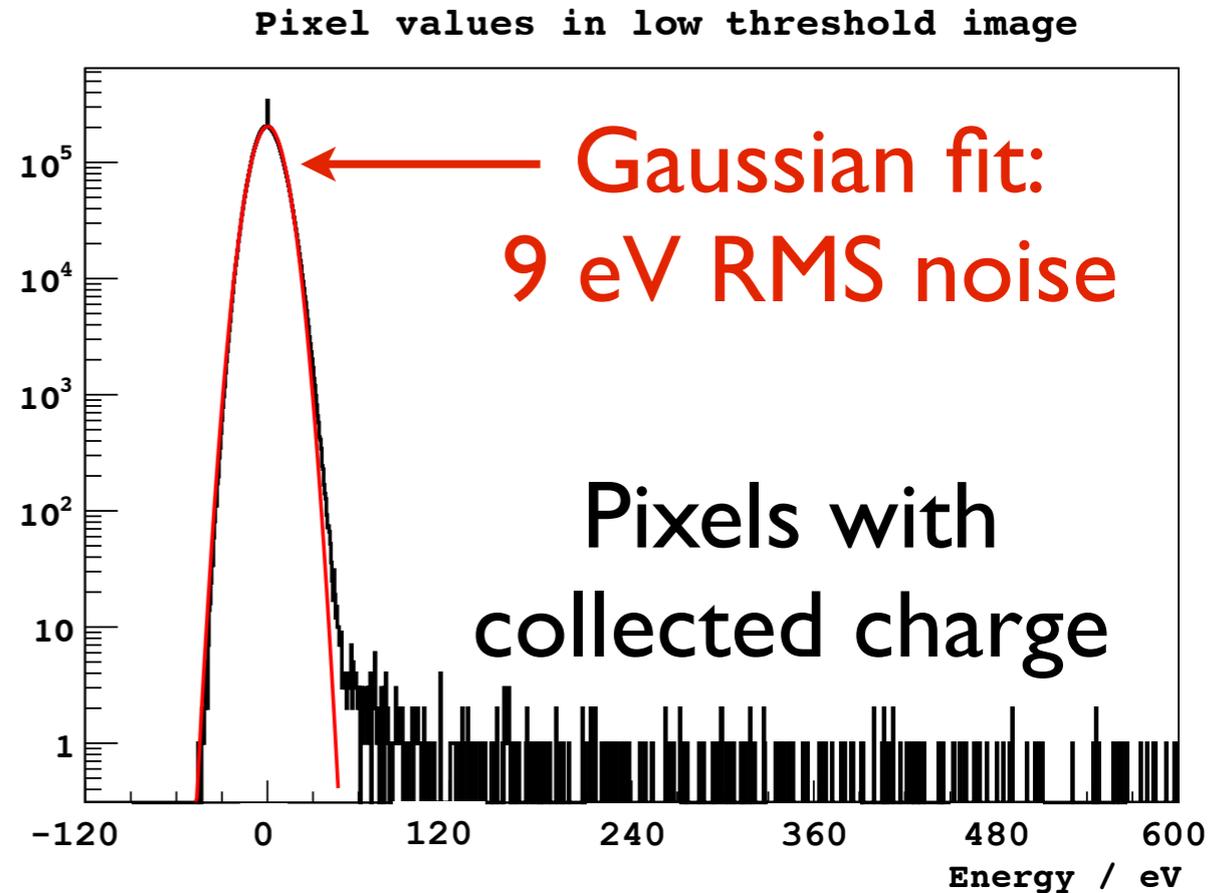


Cu box with CCDs

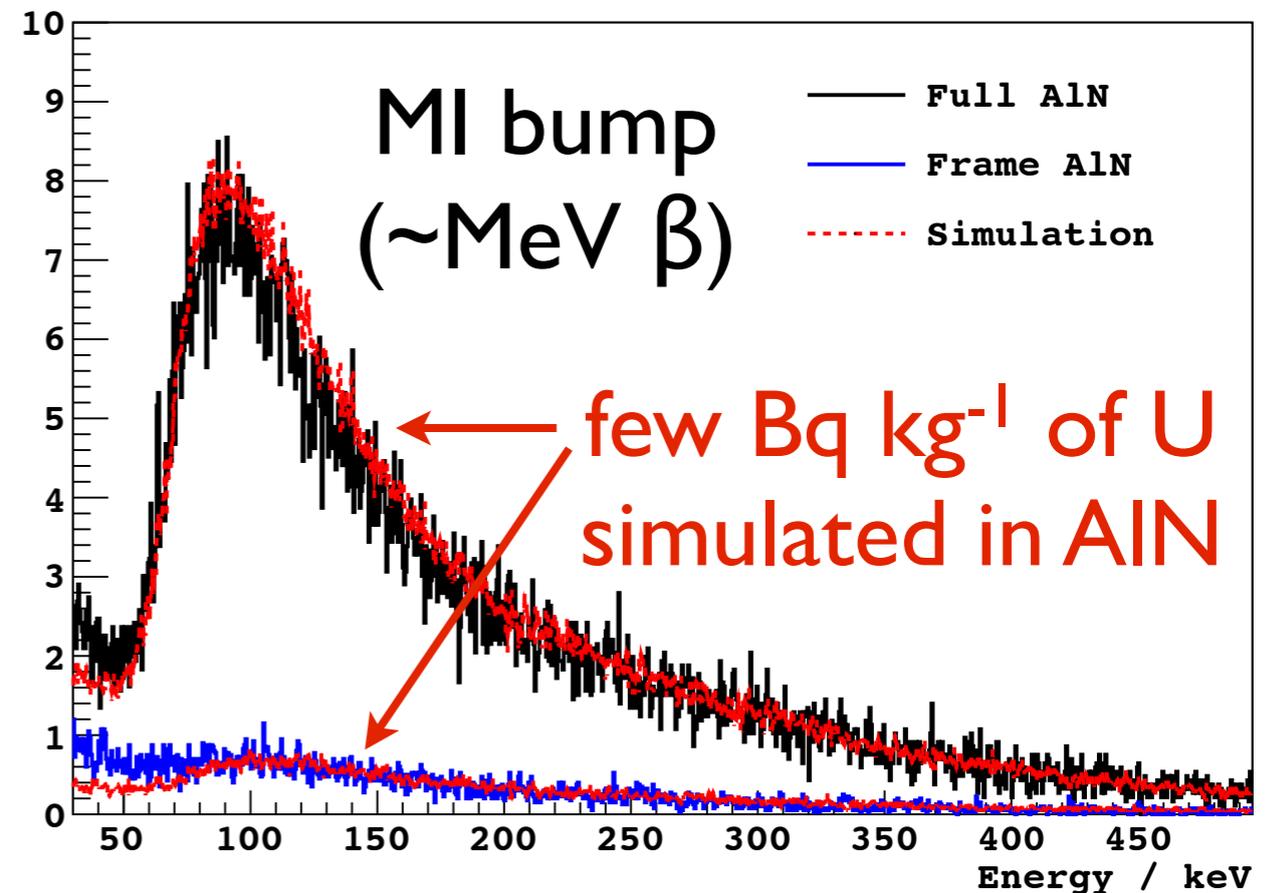
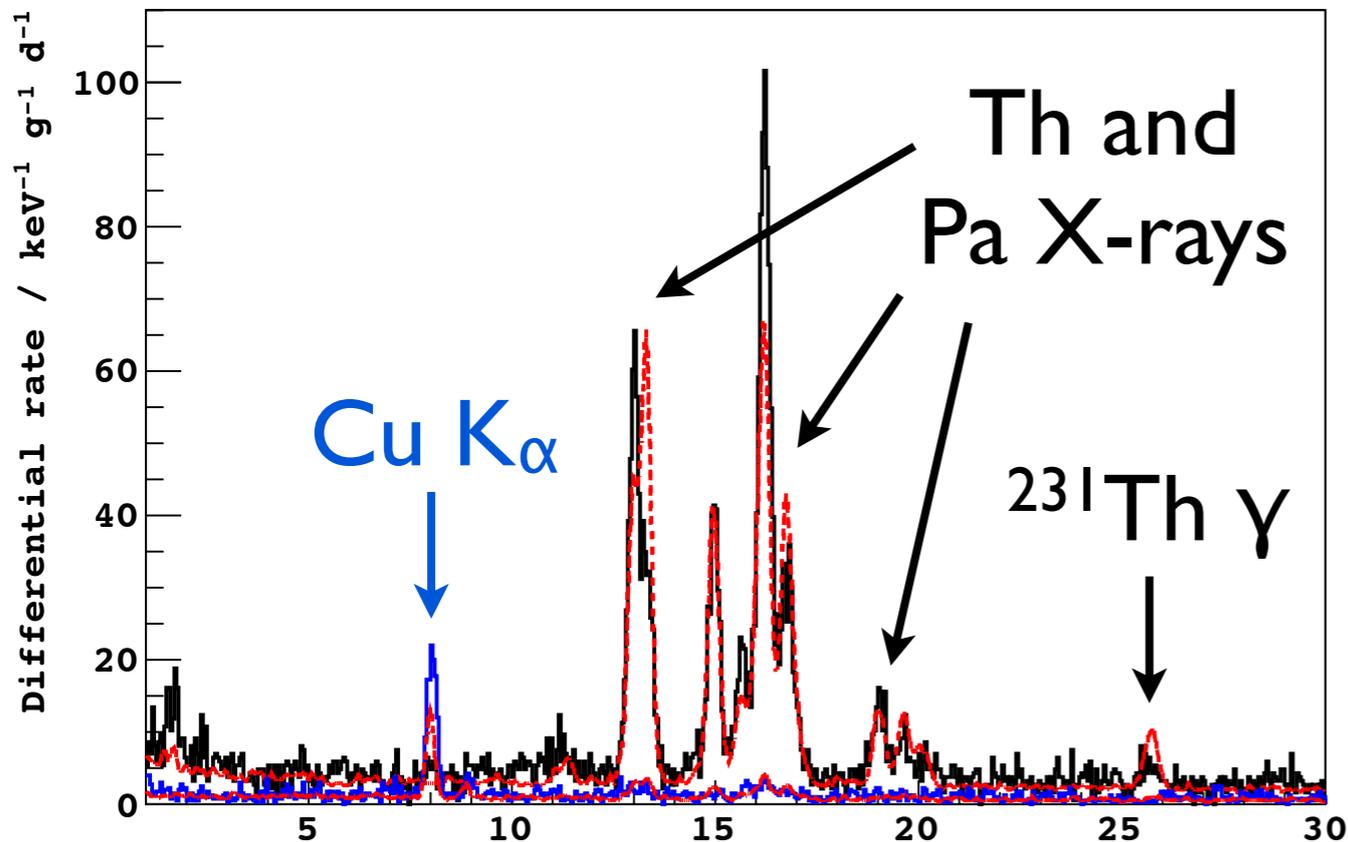


# SNOLAB data

1 g, 8 Mpixel CCDs  
6 cm x 3 cm x 250  $\mu\text{m}$   
~50 days of data  
2 CCDs with full AlN  
and 2 with **frame** AlN



Raw spectrum from CCDs at SNOLAB

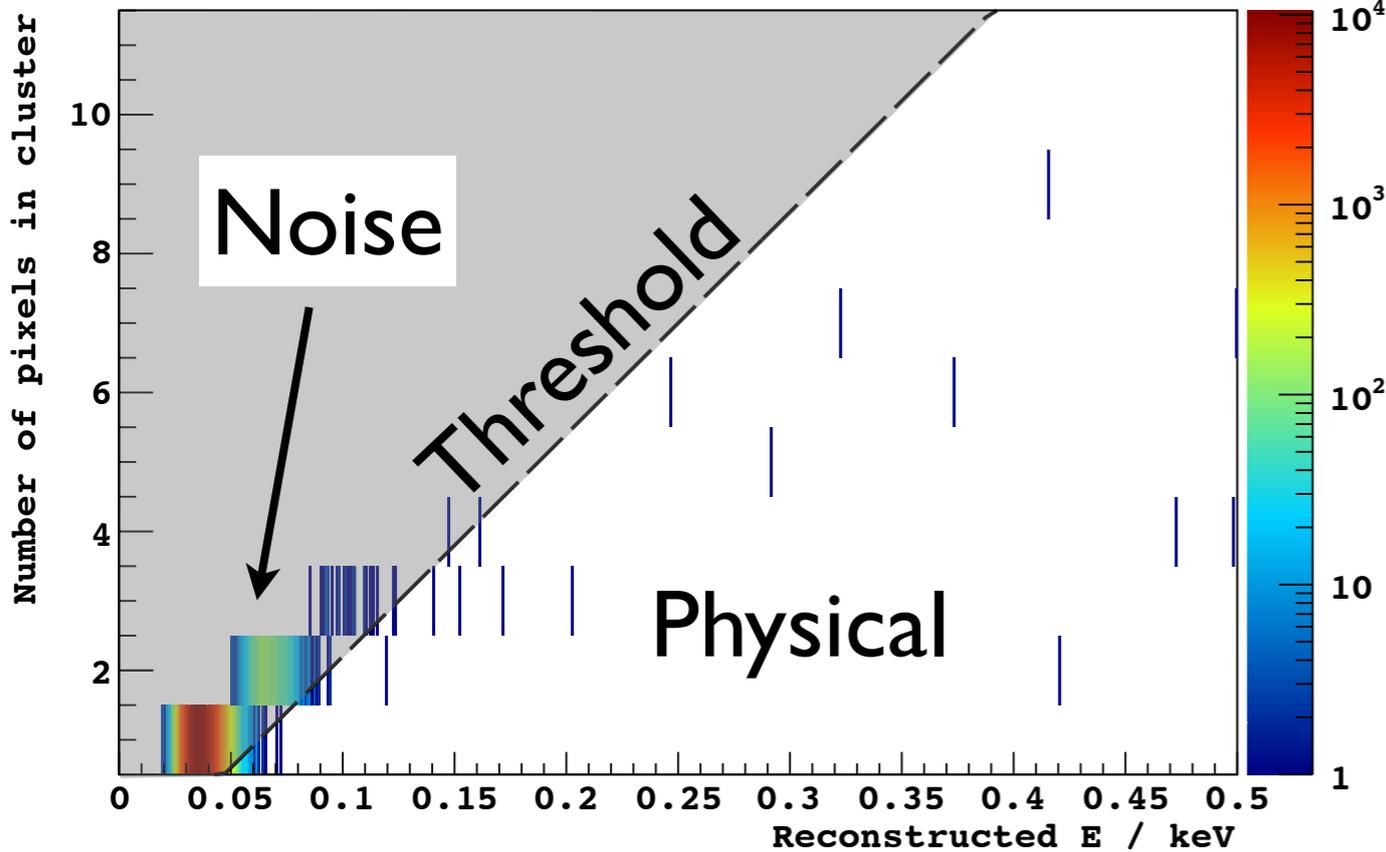


# Data selection

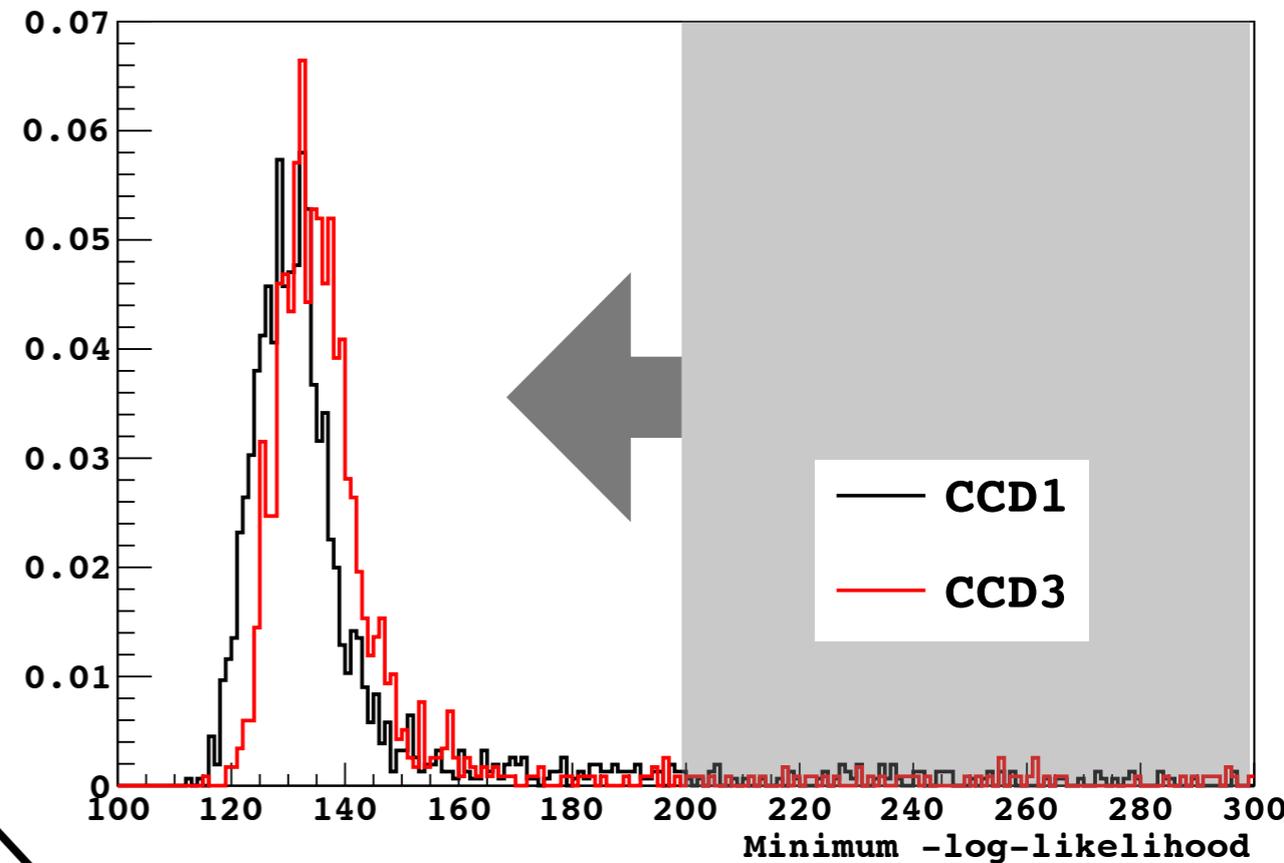
Exclude read-out noise

Select bulk events

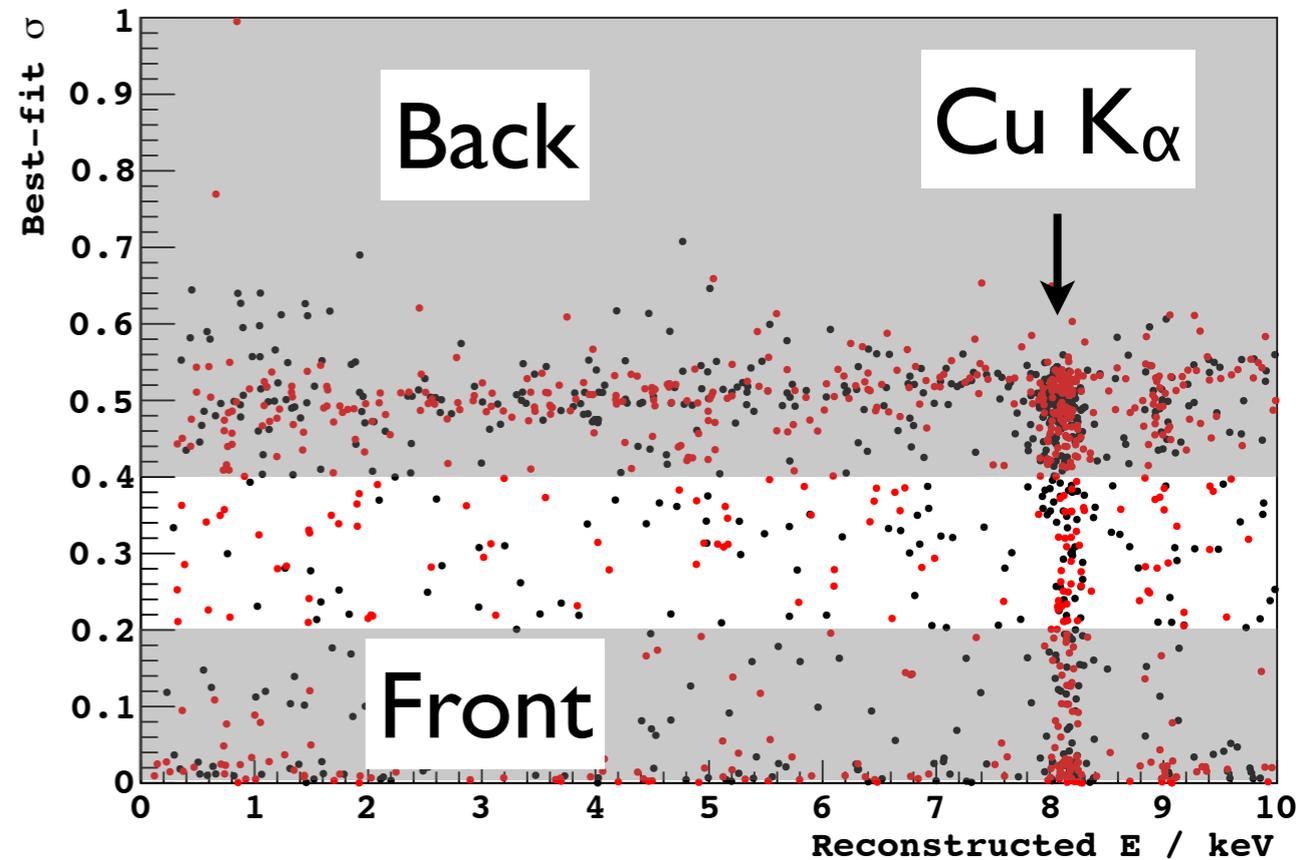
N Pixels vs E for low threshold data



Minimum -LL from  $\sigma$  fits to clusters

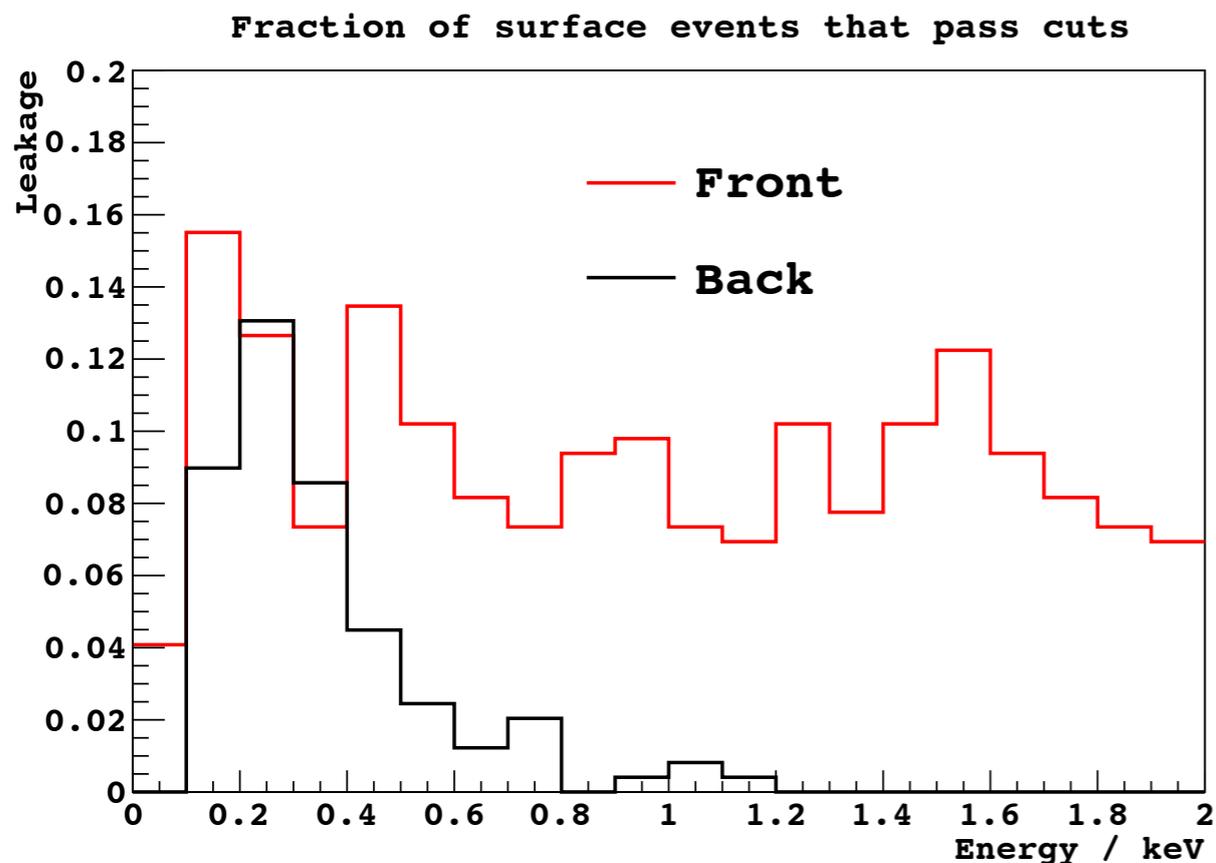


$\sigma$  vs E for frame CCDs



# Low threshold data

From simulation on  
SNOLAB blanks and data  
from  $^{252}\text{Cf}$  source

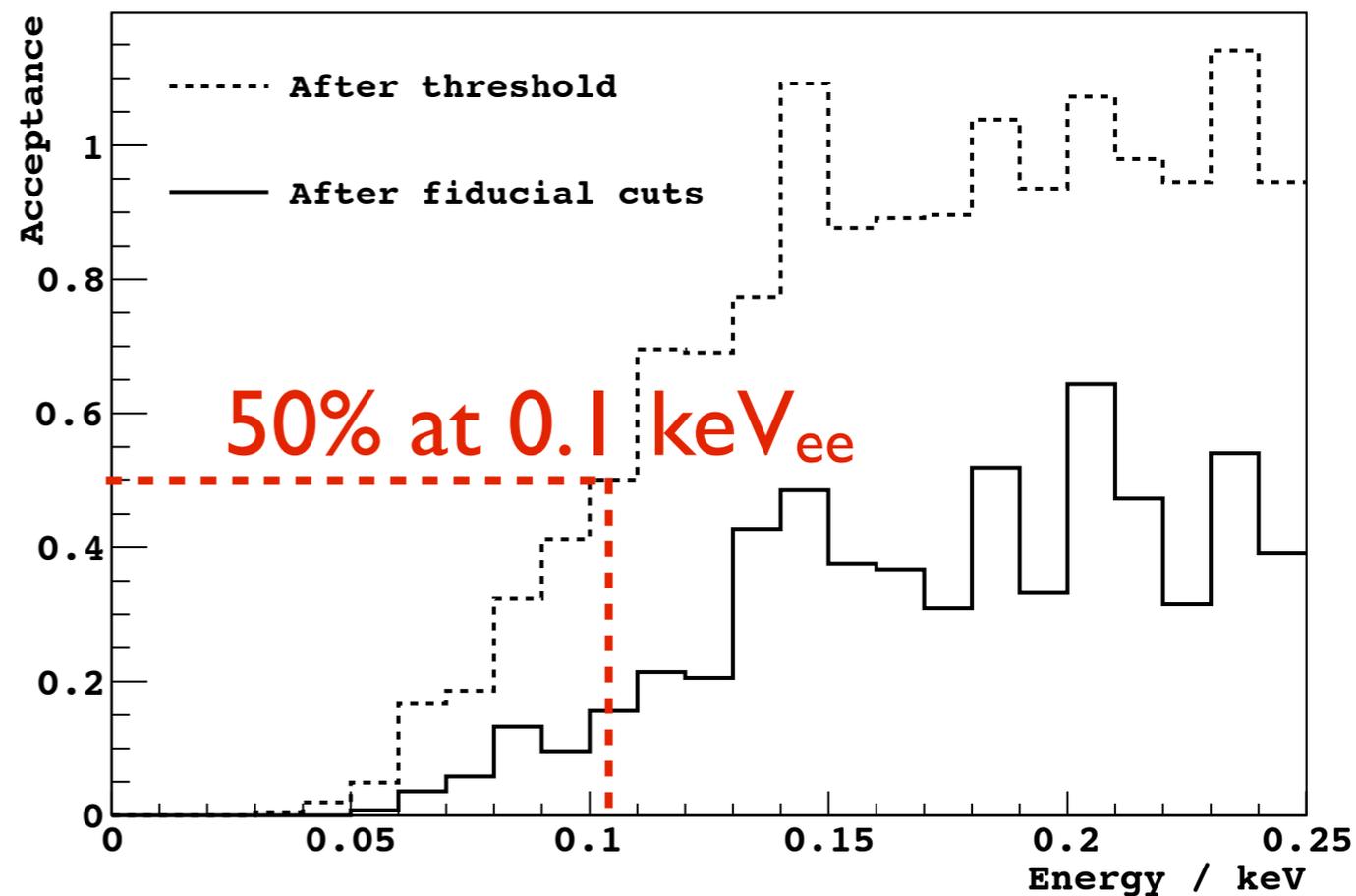


**200** read-outs  
(every 2.8 h)  
24 g d exposure

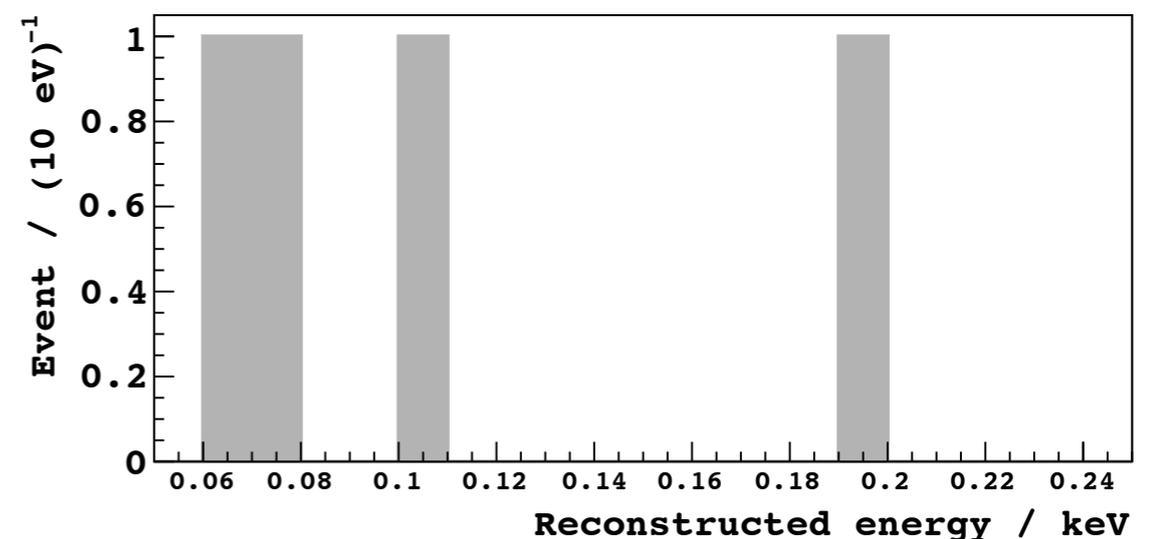


10

Acceptance for low threshold data



Candidate energy distribution



# Full data

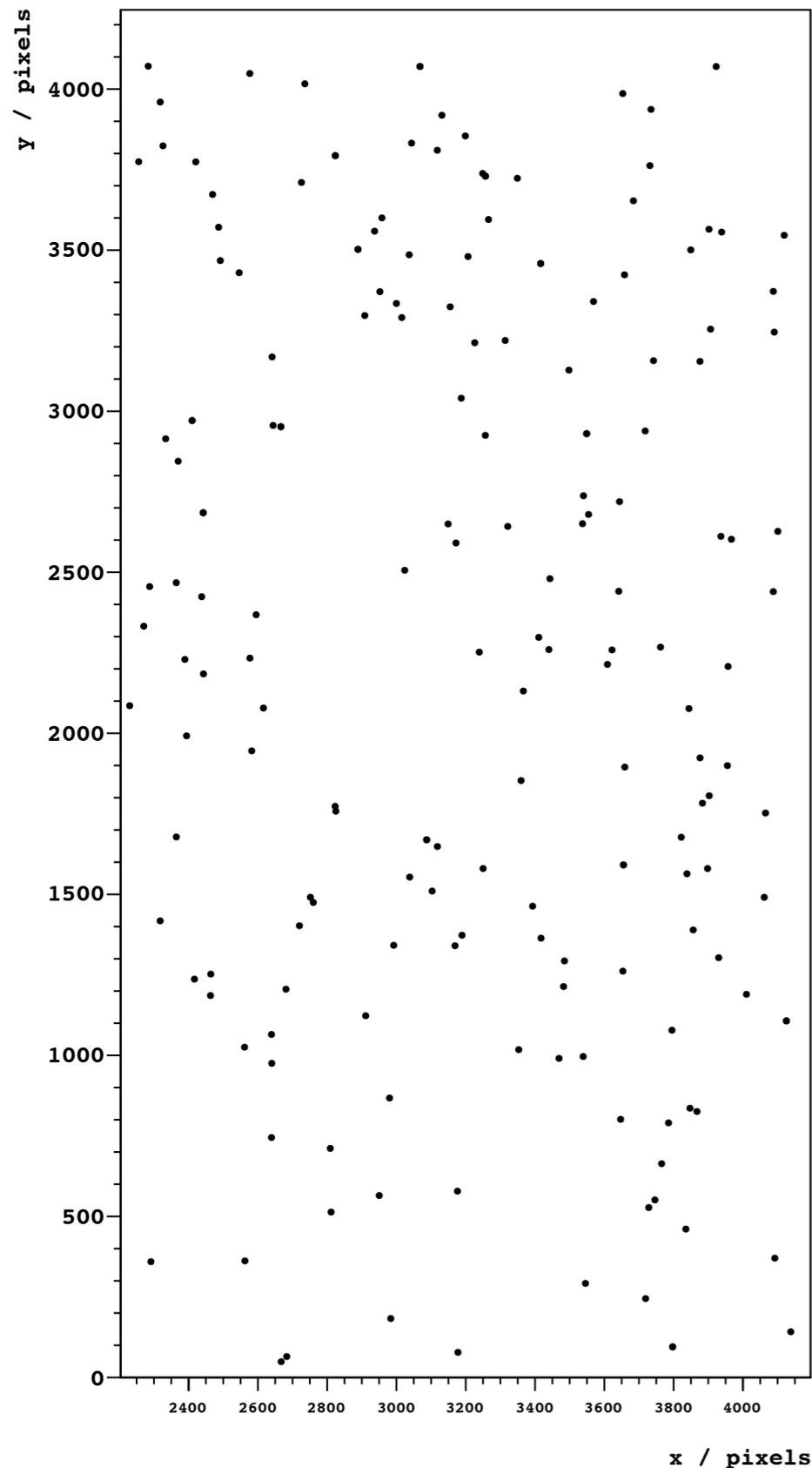
2 frame CCDs (2g)

40 days 0.3 keV threshold

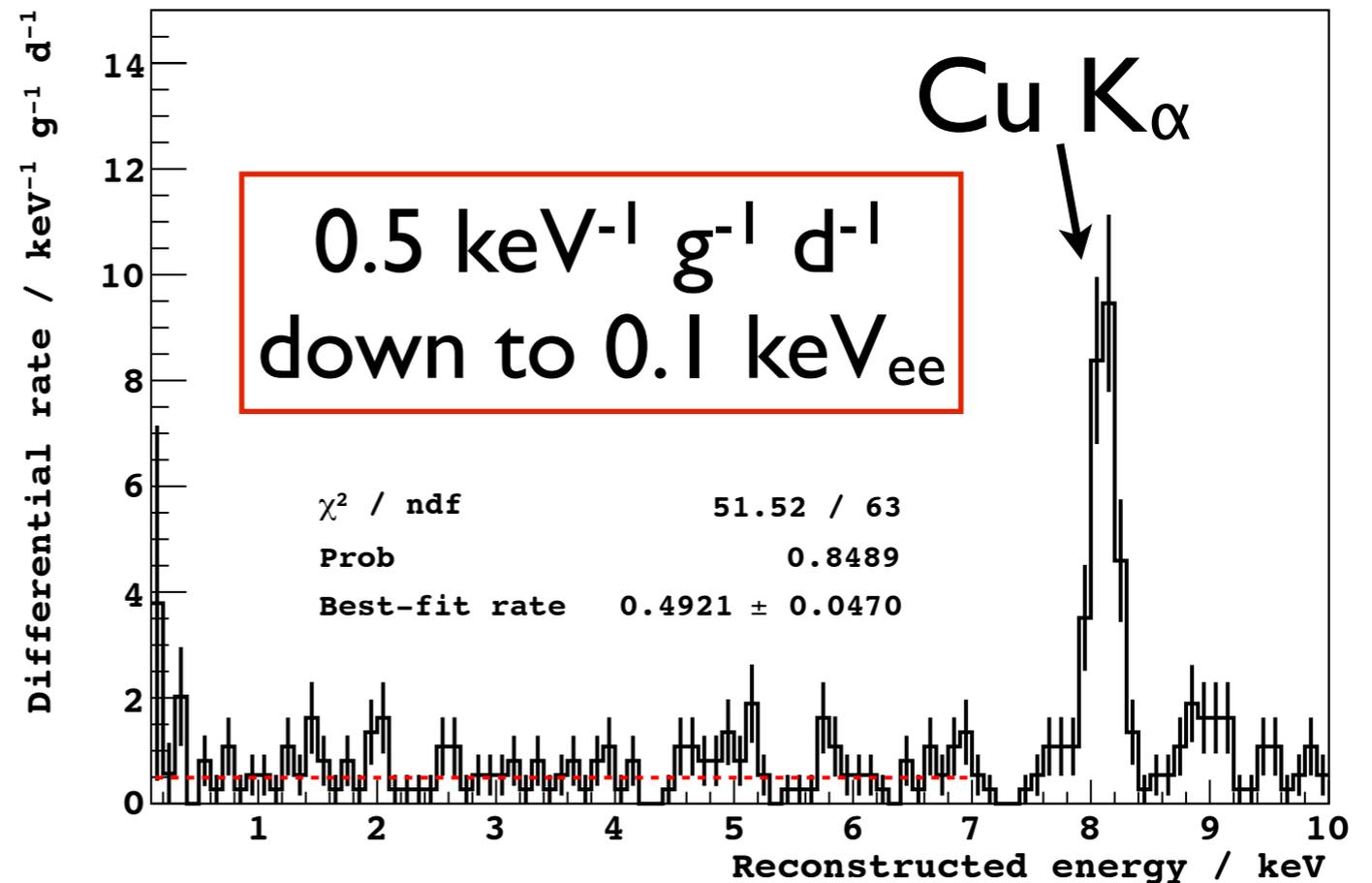
12 days 0.1 keV threshold

Fiducial cut (~35% acceptance)

Spatial distribution of final candidates <7 keV

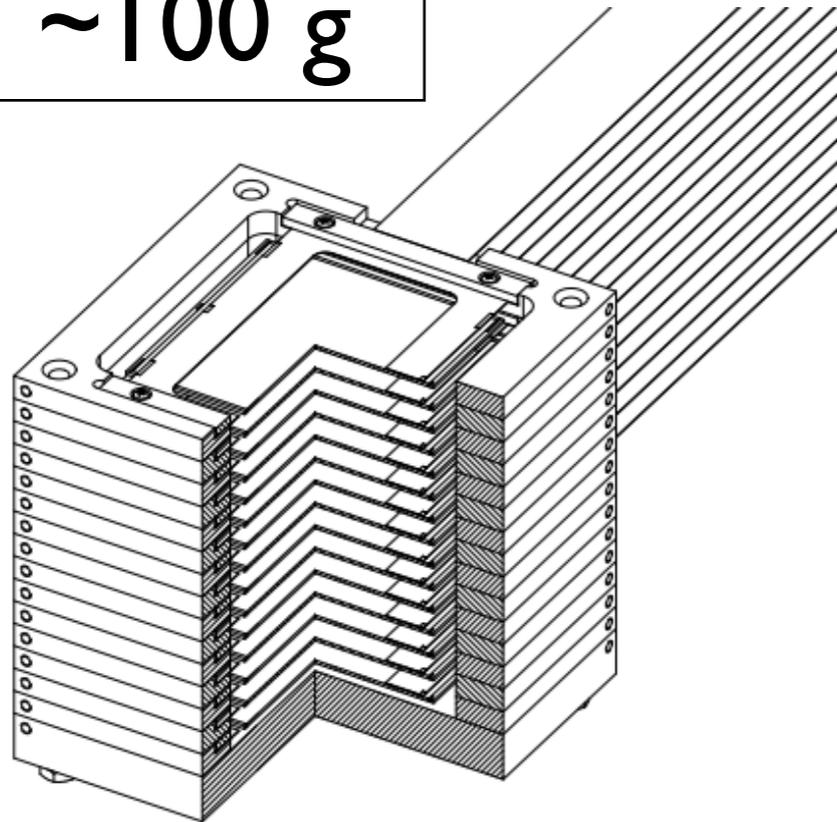


Differential spectrum after cuts

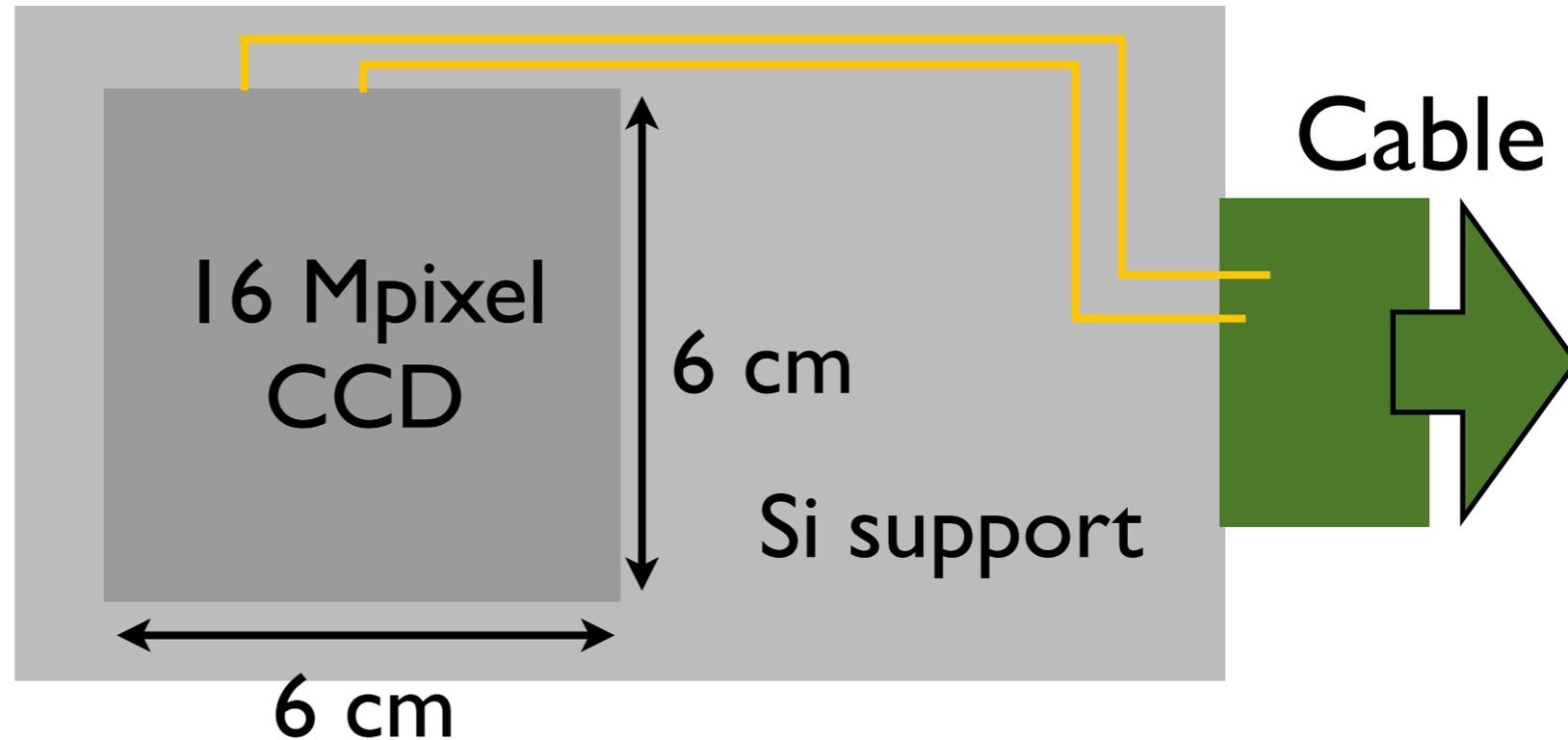


# DAMIC100

15 CCDs  
~100 g



650  $\mu\text{m}$  thick      ~20 racetracks  
printed on support



In-situ neutron background measurement with  $^{10}\text{B}$  layer

Will install 2 500  $\mu\text{m}$  thick CCDs this fall in SNOLAB.  
DAMIC100 to be deployed in current Cu vessel +  
shield in **Spring 2014**.

# Backgrounds

## CCD + support

$< 10^{-4}$  Bq kg<sup>-1</sup> of U + Th from counting  $\alpha$ s.  $\alpha$ s most likely from surface contamination  $\longrightarrow$  apply polymer film on CCD surface.

$^{32}\text{Si}$  at 300 day<sup>-1</sup>kg<sup>-1</sup> can be vetoed by the  $^{32}\text{Si} \longrightarrow ^{32}\text{P} \longrightarrow ^{32}\text{S}$  decay sequence with  $< 1\%$  loss of exposure. Similar Veto works for  $^{210}\text{Pb}$ .

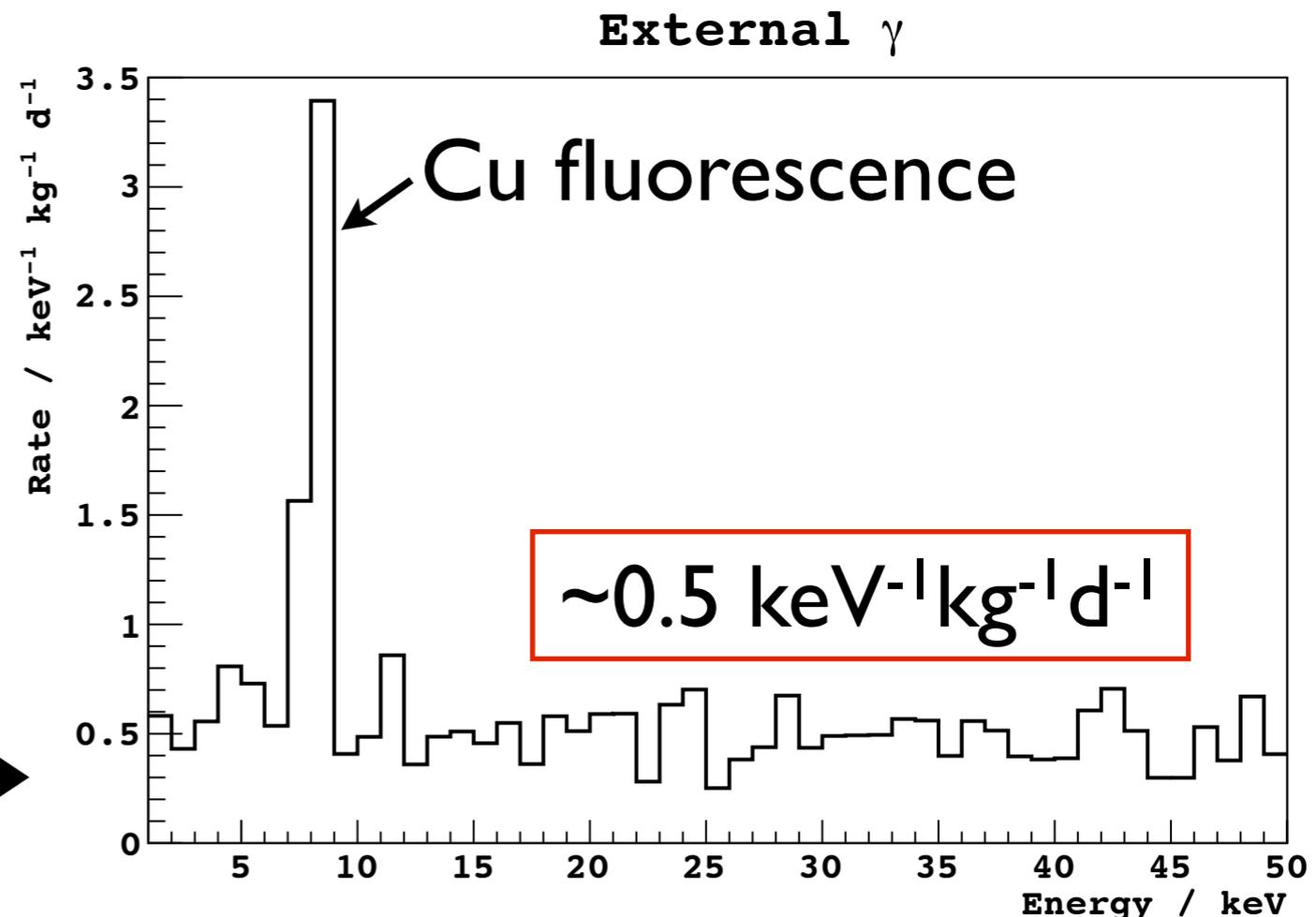
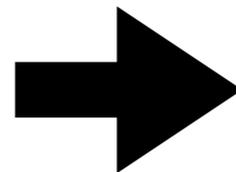
Typical analysis results of electronic-grade polysilicon (NAA and IR at RT) [4].

| Element | Atoms/cm <sup>3</sup>     |
|---------|---------------------------|
| Carbon  | $< 2.0 \times 10^{16}$ 1) |
| Oxygen  | $< 1.0 \times 10^{16}$ 1) |

... negligible  $^{14}\text{C}$ , etc.

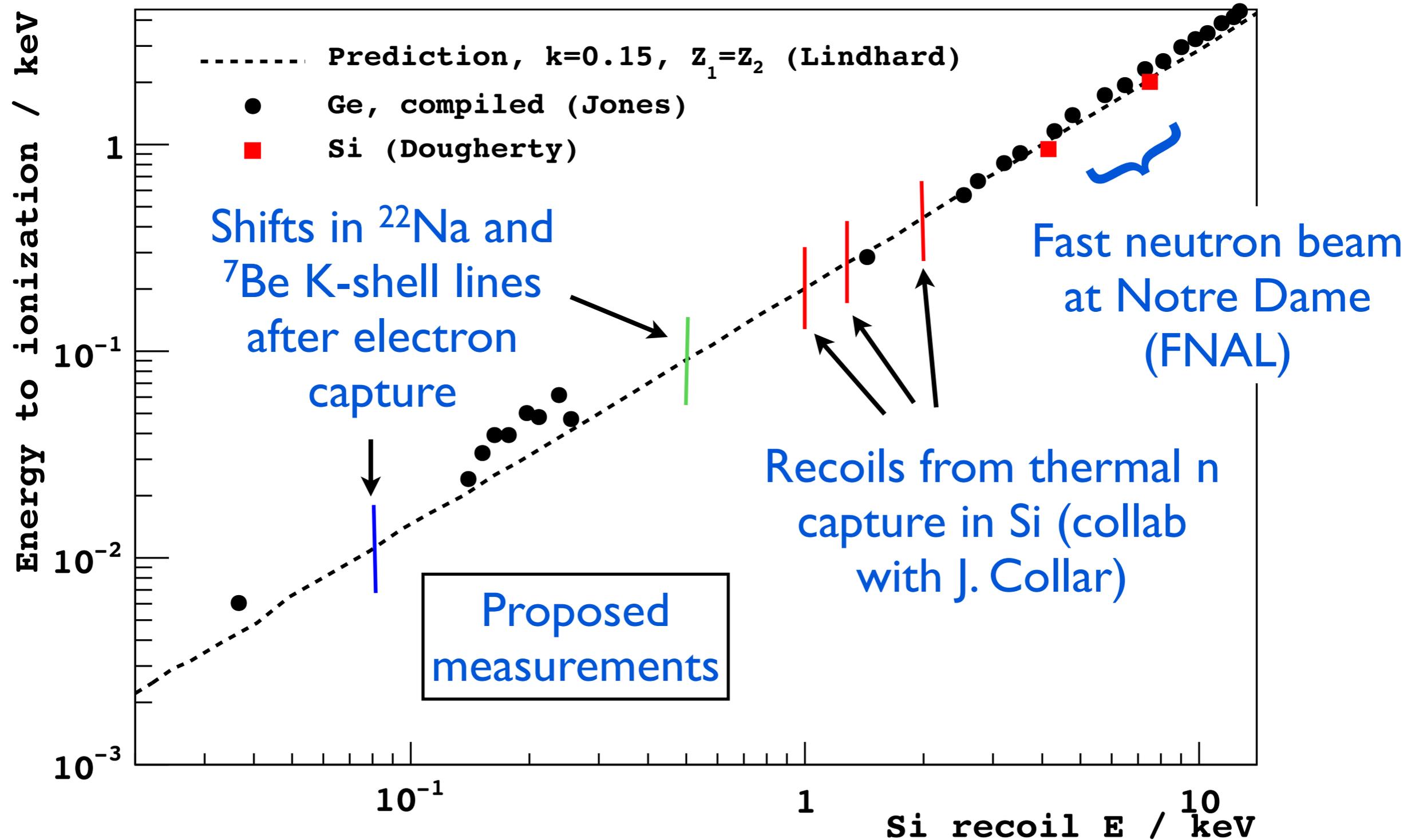
Need to be careful about Epoxy

Goal: to be dominated by external  $\gamma$



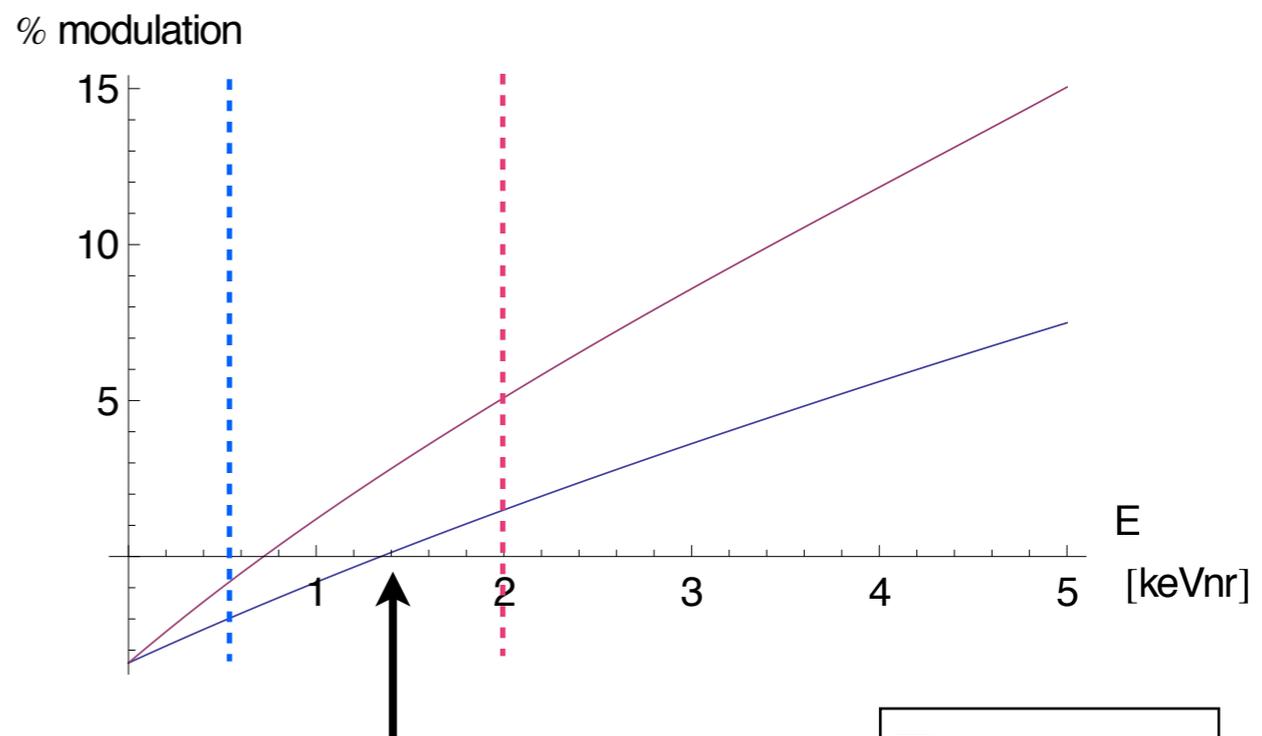
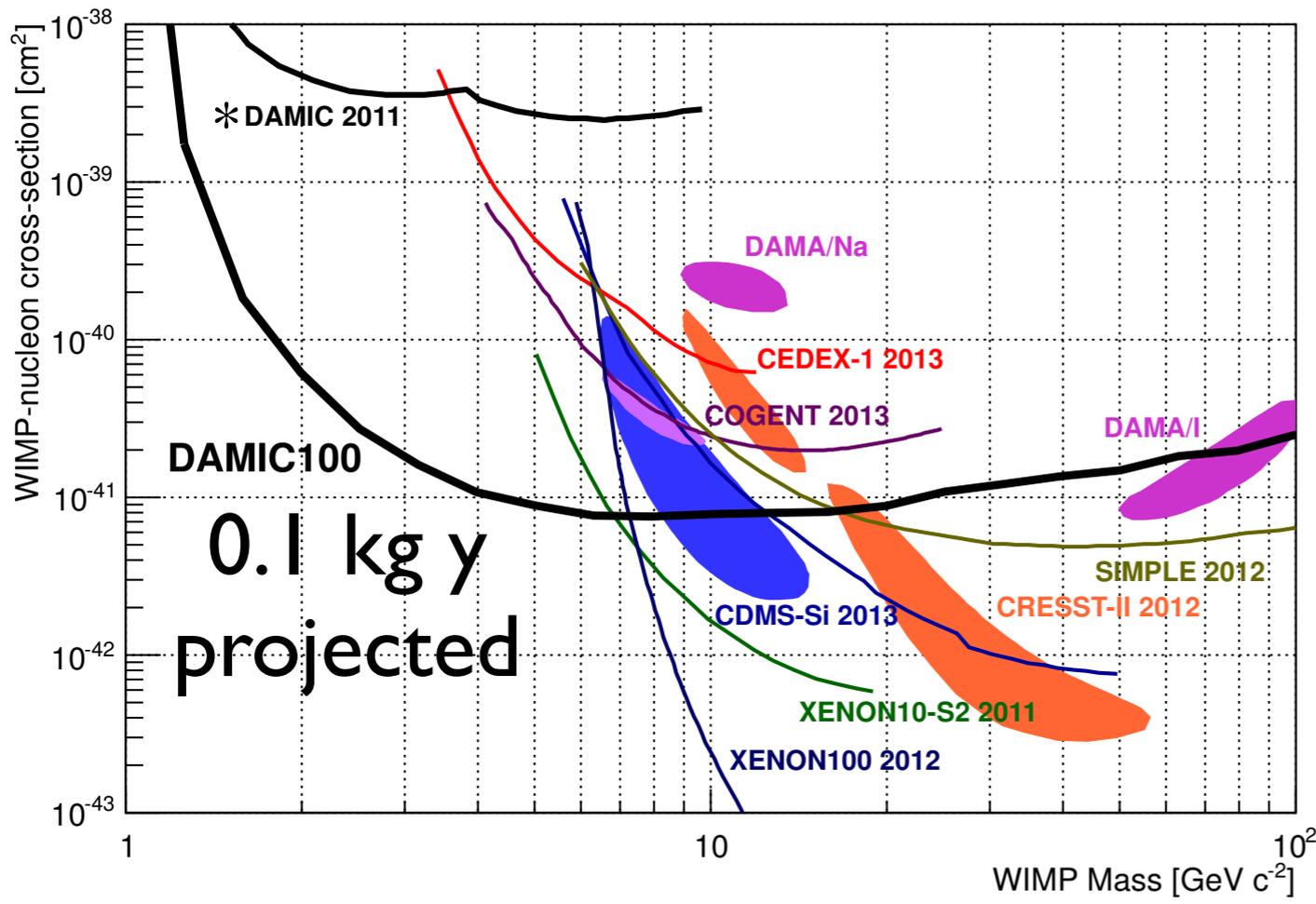
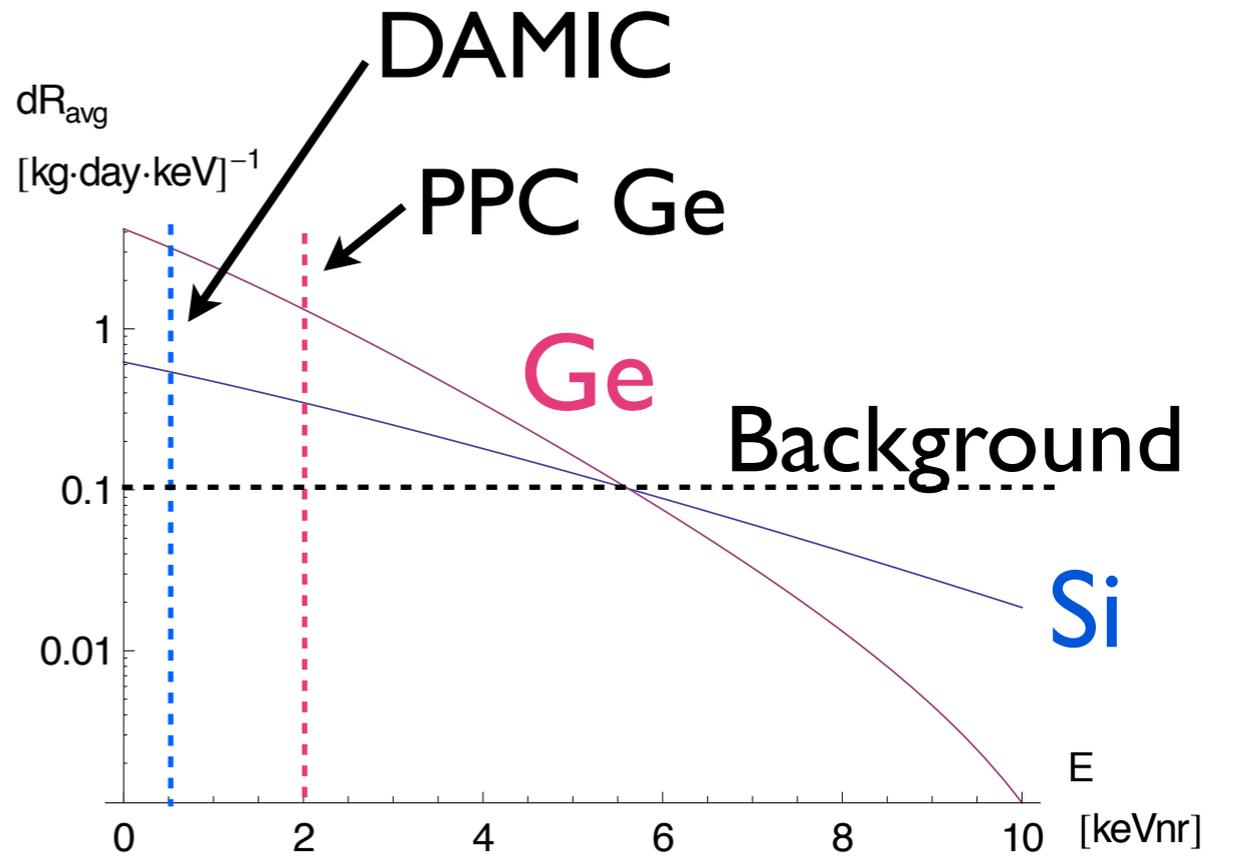
# Calibration of $E_r$ scale

Results for ionization efficiency in low E regime



# Sensitivity

DAMIC 100 is well-suited to explore the CDMS-Si result



\*Physics Lett. B711 (2012) 264-269

Phase inversion

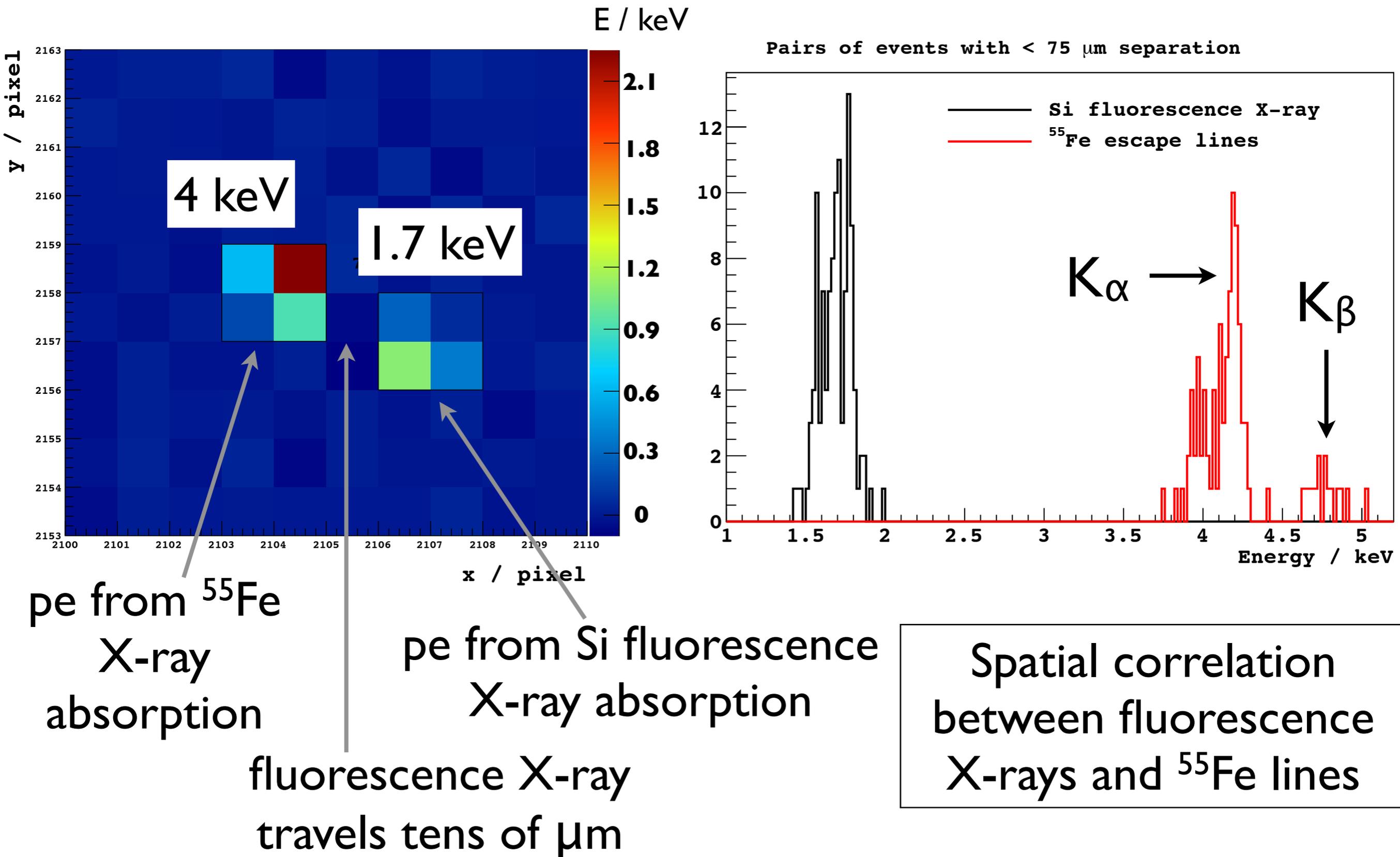
Tongyan Lin

# Conclusion

- DAMIC is running at SNOLAB.
- Strong calibration program.
- Demonstrated 9 eV RMS pixel noise.
- Demonstrated potential for depth reconstruction in CCD bulk.
- Identified U in AlN as main source of background.
- No known background seems unsurmountable.
- DAMIC100 will be deployed in Spring 2014 and directly test CDMS-Si result.

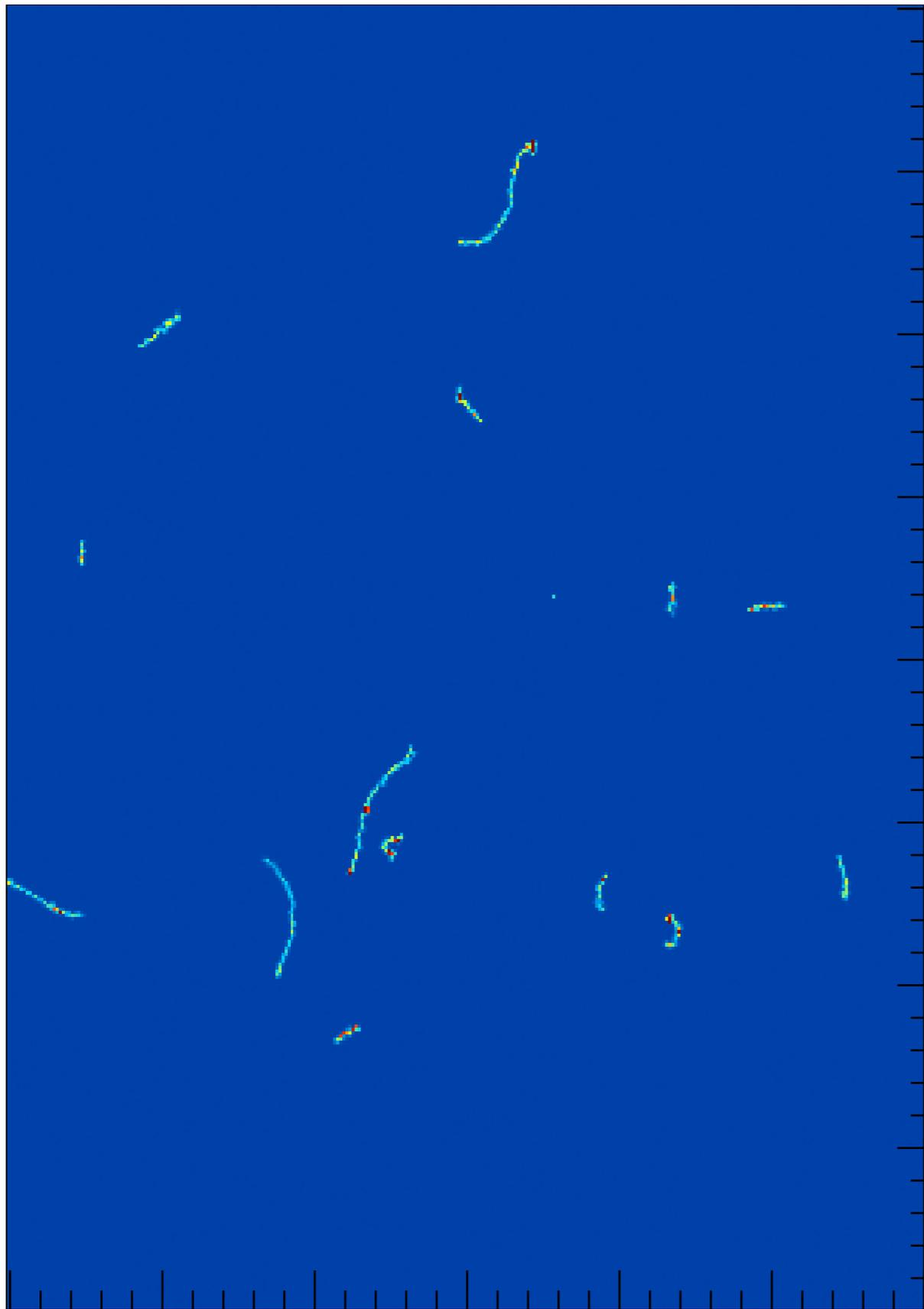
# **Backup Slides**

# Spatial correlation in $^{55}\text{Fe}$

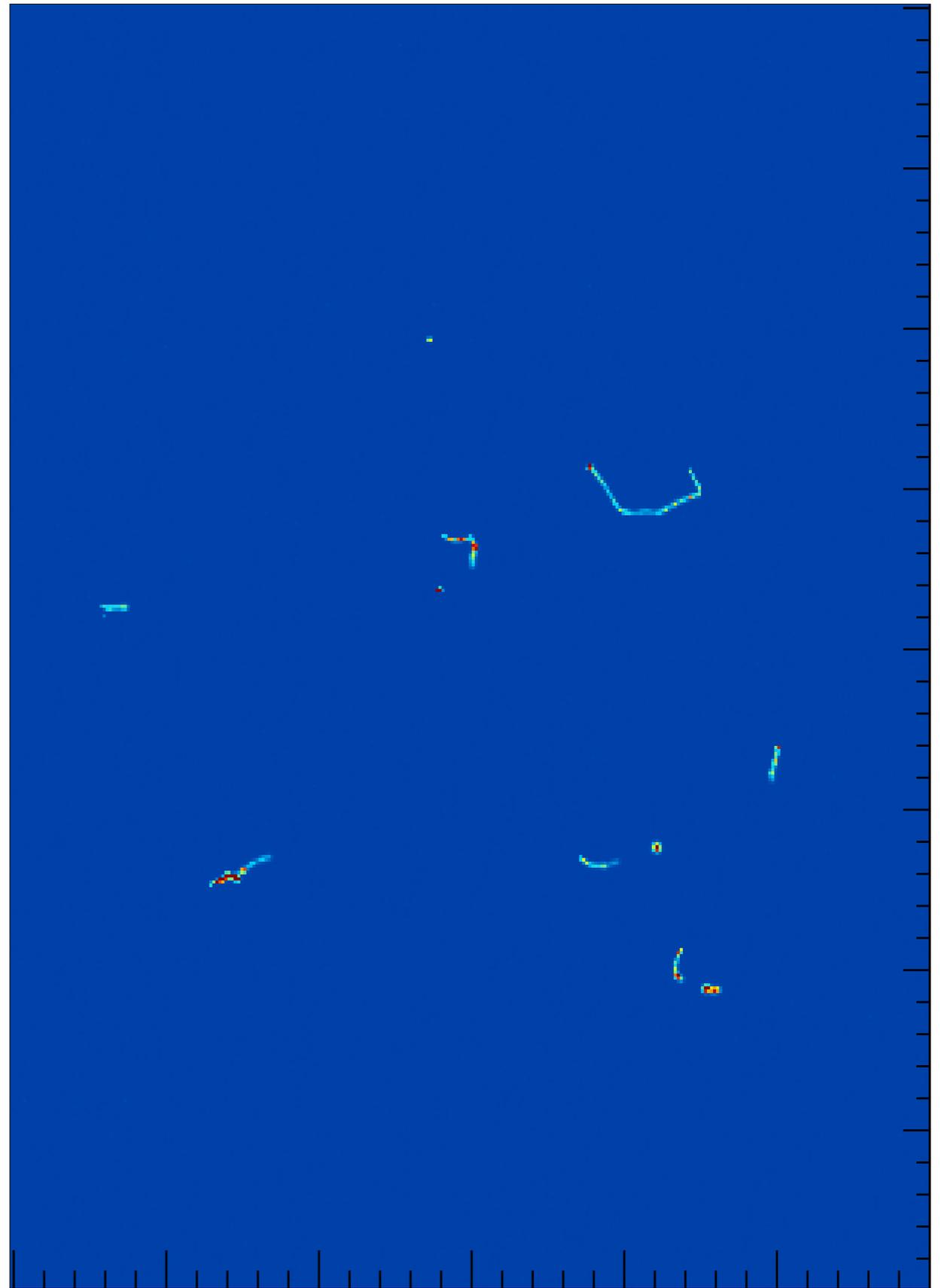


# MCNPX Simulation

- We have started a DAMIC simulation based on MCNPX.
- Given a particle source, we get energy deposits in a mesh the size of the CCD image.
- We also store the mean  $x$ ,  $y$  and  $z$  positions of the deposits in the cell.
- We use this information with some noise + diffusion models to construct fake image.



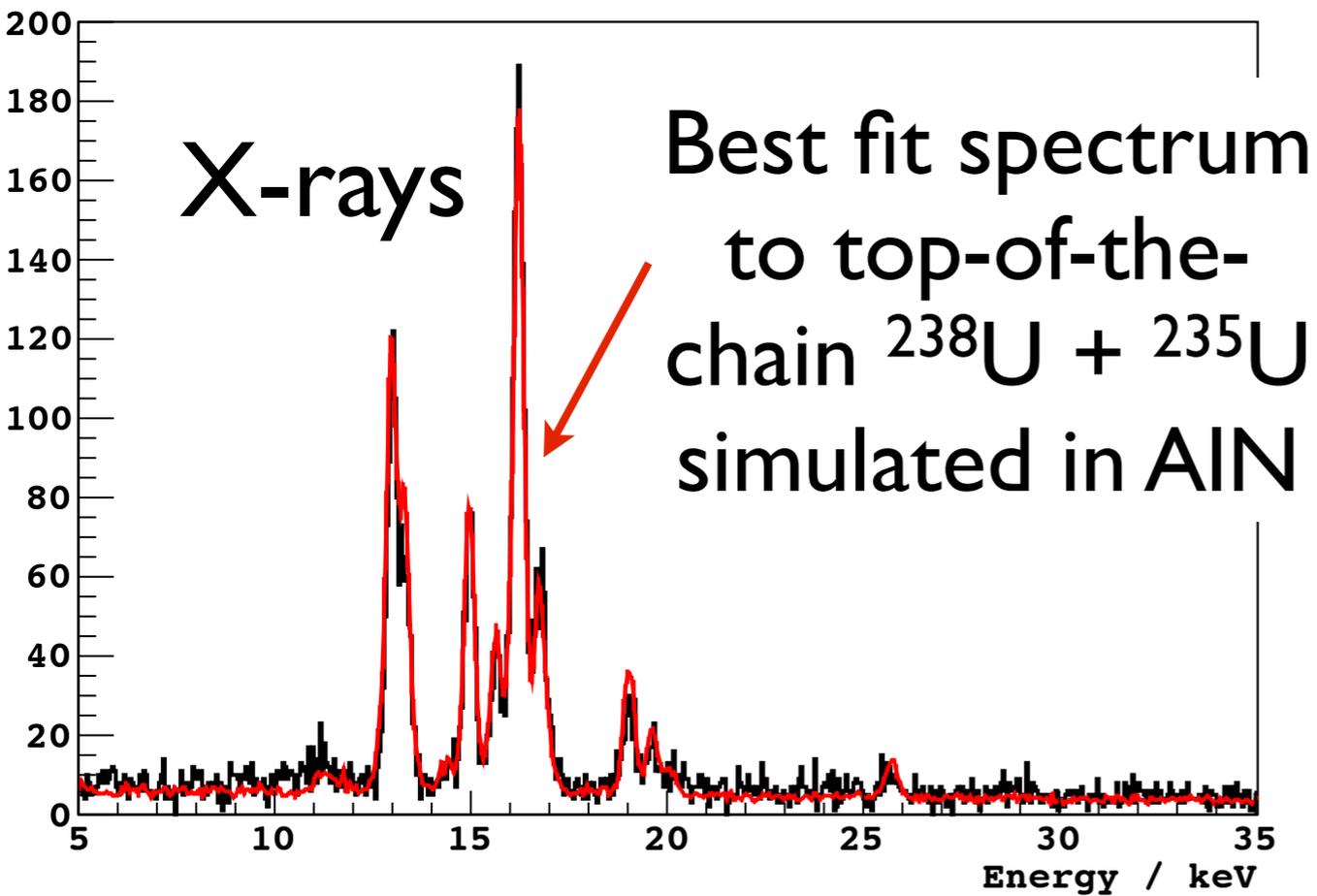
Simulated  $\beta$ s



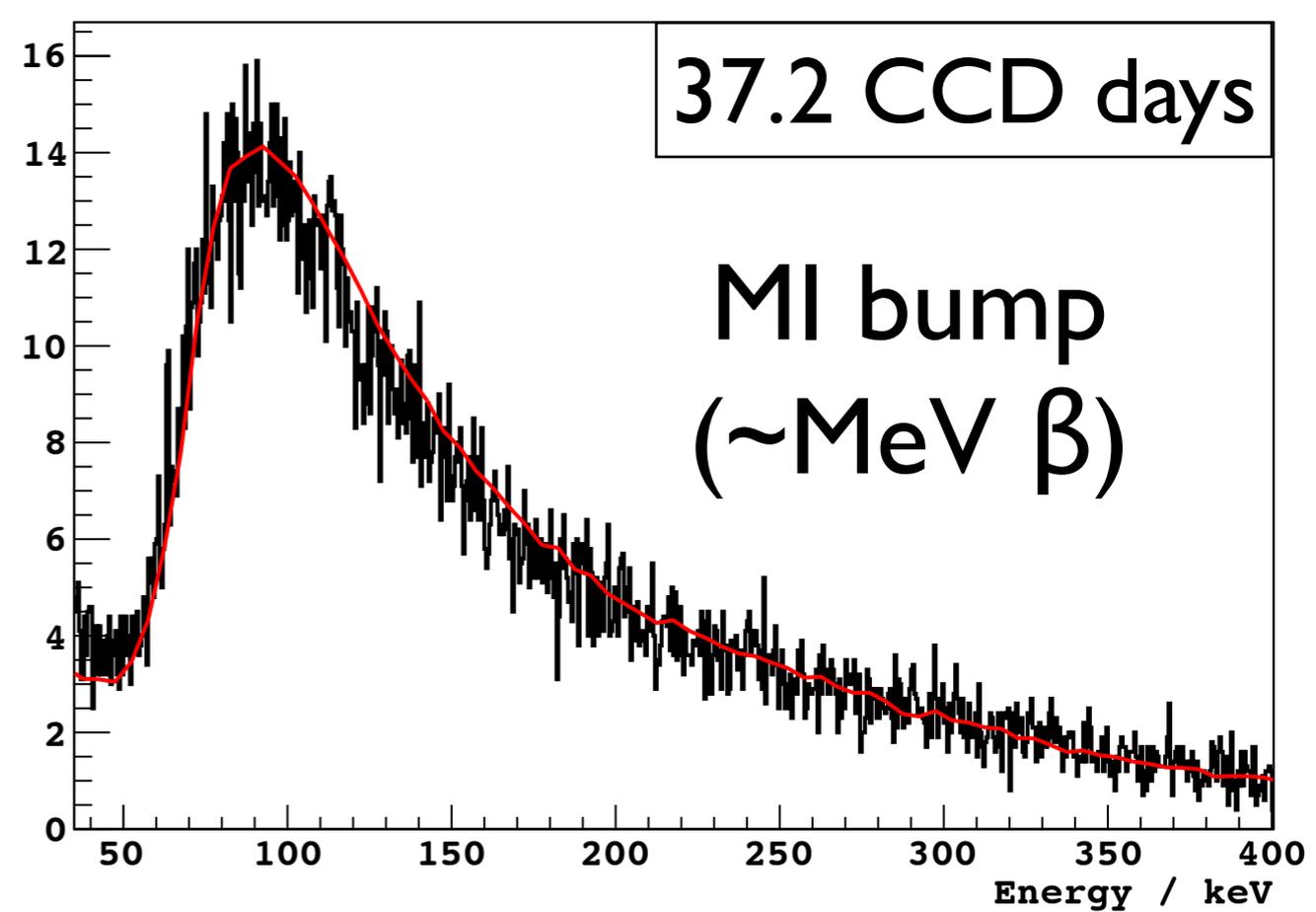
Data

# DAMIC full AIN spectrum

x2 and x3 for runs 1688 - 1843



x2 and x3 for runs 1688 - 1843



mBq / kg

|                   |                |
|-------------------|----------------|
| $^{235}\text{U}$  | $330 \pm 30$   |
| $^{238}\text{U}$  | $4110 \pm 530$ |
| $^{226}\text{Ra}$ | $42 \pm 9$     |
| $^{232}\text{Th}$ | $32 \pm 8$     |

SNOLAB  $\gamma$ -ray measurement of AIN

} ppb levels

U is very dim in  $\gamma$  but very bright in X-rays.

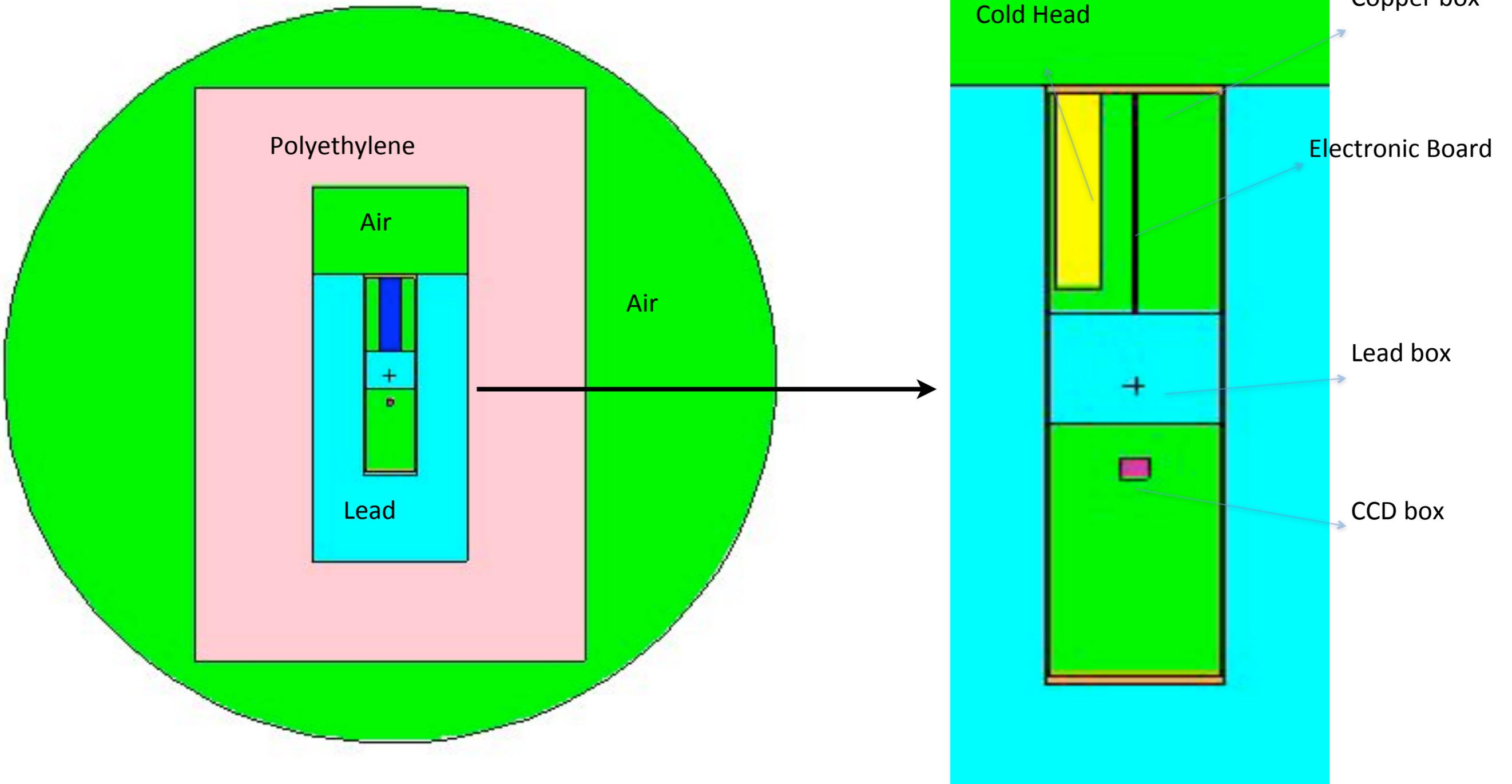
# n backgrounds

| Source                   | Collisions in 5 g x<br>1000 days | Ref          |
|--------------------------|----------------------------------|--------------|
| $\mu$ in Shield          | <0.1                             | BX<br>ZEPLIN |
| Norite rock              | <0.001                           | COUPP        |
| ( $\alpha$ ,n) in shield | <0.1                             | ZEPLIN       |

COUPP-4 was “dirty” (4 kg of borosilicate glass with ppm of U, piezoelectric transducers next to active volume) and it saw  $\sim 0.25$  bubbles  $\text{kg}^{-1}\text{d}^{-1}$ .

Even that level not a problem for us.

# Geometry



# Contamination

| Cell            | Material                   | Mass     | $^{238}\text{U}$ | $^{232}\text{Th}$ | $^{40}\text{K}$ | $^{210}\text{Pb}$ | $^{60}\text{Co}$ | Ref            |
|-----------------|----------------------------|----------|------------------|-------------------|-----------------|-------------------|------------------|----------------|
| Electronic Card | Teflon/PCB                 | 105 g    | 100 mBq          | 3 mBq             | 35 mBq          | -                 | -                | GERDA PZ0      |
| Cold head       | Iron/Steel                 | 4.5 kg   | 1 ppb            | 5 ppb             | 0.3 ppm         | -                 | 25 mBq / kg      | ILIAS BX       |
| Pb block above  | Pb                         | 50.7 kg  | 10 ppt           | 10 ppt            | 5 ppb           | 20 Bq/kg          | -                | EXO DoeRun     |
| Copper vessel   | Cu                         | 29.5 kg  | 10 ppt           | 10 ppt            | 5 ppb           | -                 | 0.6 mBq / kg     | EXO, DS ZEPLIN |
| Pb shield       | Pb                         | 4.94 ton | 10 ppt           | 10 ppt            | 5 ppb           | 20 Bq/kg          | -                | EXO DoeRun     |
| Poly shield     | $(\text{C}_2\text{H}_4)_n$ | 4.57 ton | 5 ppb            | 5 ppb             | 5 ppm           | -                 | -                | ILIAS          |

**Black - upper limits**

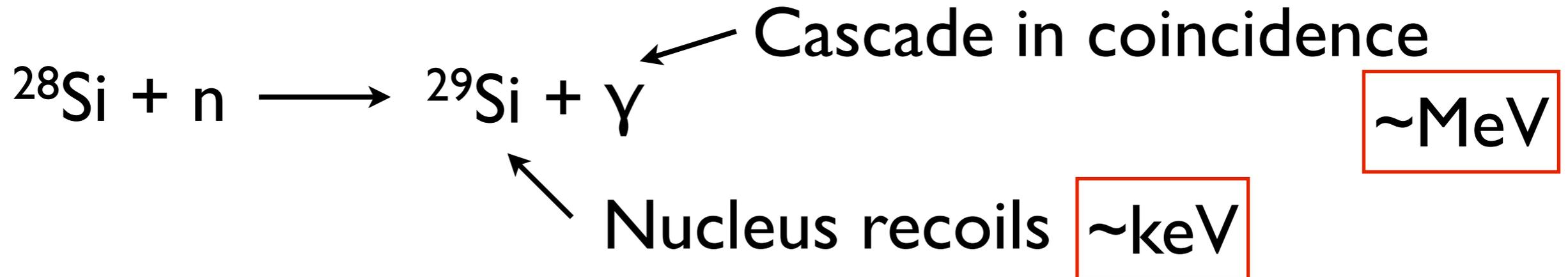
**Blue - characteristic values**

# Number of collisions from $\gamma$ s in a 5 g of Si in 1000 days

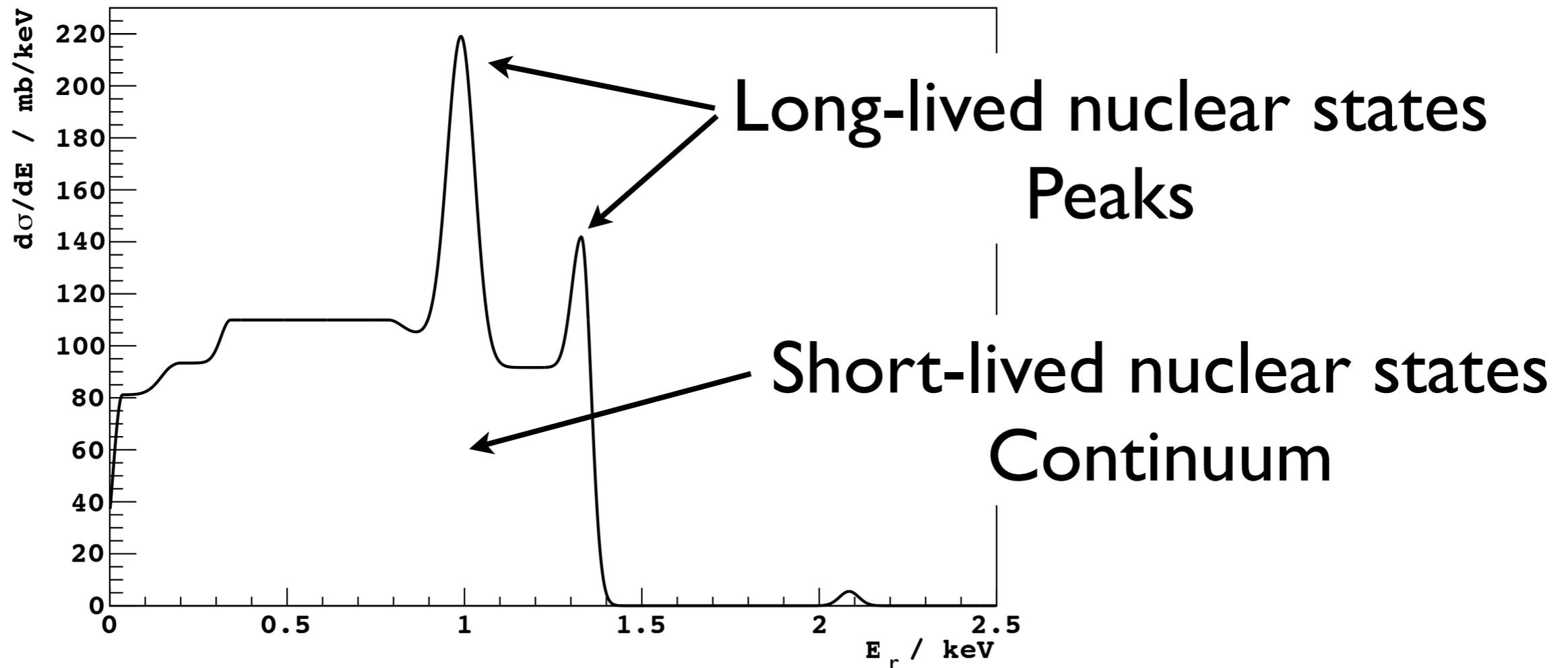
| Cell            | Material                   | Mass     | $^{238}\text{U}$ | $^{232}\text{Th}$ | $^{40}\text{K}$ | $^{210}\text{Pb}$ | $^{60}\text{Co}$ | Ref            |       |
|-----------------|----------------------------|----------|------------------|-------------------|-----------------|-------------------|------------------|----------------|-------|
| Electronic Card | Teflon/PCB                 | 105 g    | <0.26            | 0.005             | <0.09           | -                 | -                | GERDA PZ0      |       |
| Cold head       | Iron/Steel                 | 4.5 kg   | <0.14            | 0.078             | 0.11            | -                 | <0.29            | ILIAS BX       |       |
| Pb block above  | Pb                         | 50.7 kg  | 20.3             | 4.44              | 2.65            | 21.2              | -                | EXO DoeRun     |       |
| Copper vessel   | Cu                         | 29.5 kg  | 64.8             | 14.7              | 8.34            | -                 | 291              | EXO, DS ZEPLIN |       |
| Pb shield       | Pb                         | 4.94 ton | 120.6            | 26.16             | 15.84           | 129.8             | -                | EXO DoeRun     |       |
| Poly shield     | $(\text{C}_2\text{H}_4)_n$ | 4.57 ton | 0.74             | 0.95              | <0.6            | -                 | -                | ILIAS          |       |
| Rock            | Norite                     | a lot    | 3.6              |                   |                 |                   |                  |                | COUPP |

Shielding good enough so that the main background contribution is from the shielding itself.

# Thermal neutron capture



Recoil spectrum from n captures in Si



# CCD activation at a proton beam

| Isotope            | Half-life | Si(p,x)<br>mb | Activation  | EC prob. | $\frac{E_\gamma}{\text{keV}}$ | $\frac{E_K}{\text{eV}}$ | $\frac{\sigma_K}{\text{eV}}$ | $\frac{E_R}{\text{eV}}$ | $\frac{\delta E}{\text{eV}}$ |
|--------------------|-----------|---------------|---|----------|-------------------------------|-------------------------|------------------------------|-------------------------|------------------------------|
|                    | days      |               | $\text{Bq g}^{-1} (10^{10} \text{ p cm}^{-2})^{-1}$ |          | keV                           | eV                      | eV                           | eV                      | eV                           |
| ${}^7\text{Be}$    | 53.12     | 3.2           | 0.103   | 1.000    | 477.6                         | 55                      | 7                            | 57 + 0                  | 10                           |
| ${}^{22}\text{Na}$ | 950.3     | 15.8          | 0.029   | 0.097    | 1275                          | 870                     | 28                           | 60 + 40                 | 14                           |

Long lived  
EC isotopes

For 230 MeV  
 $p$  beam

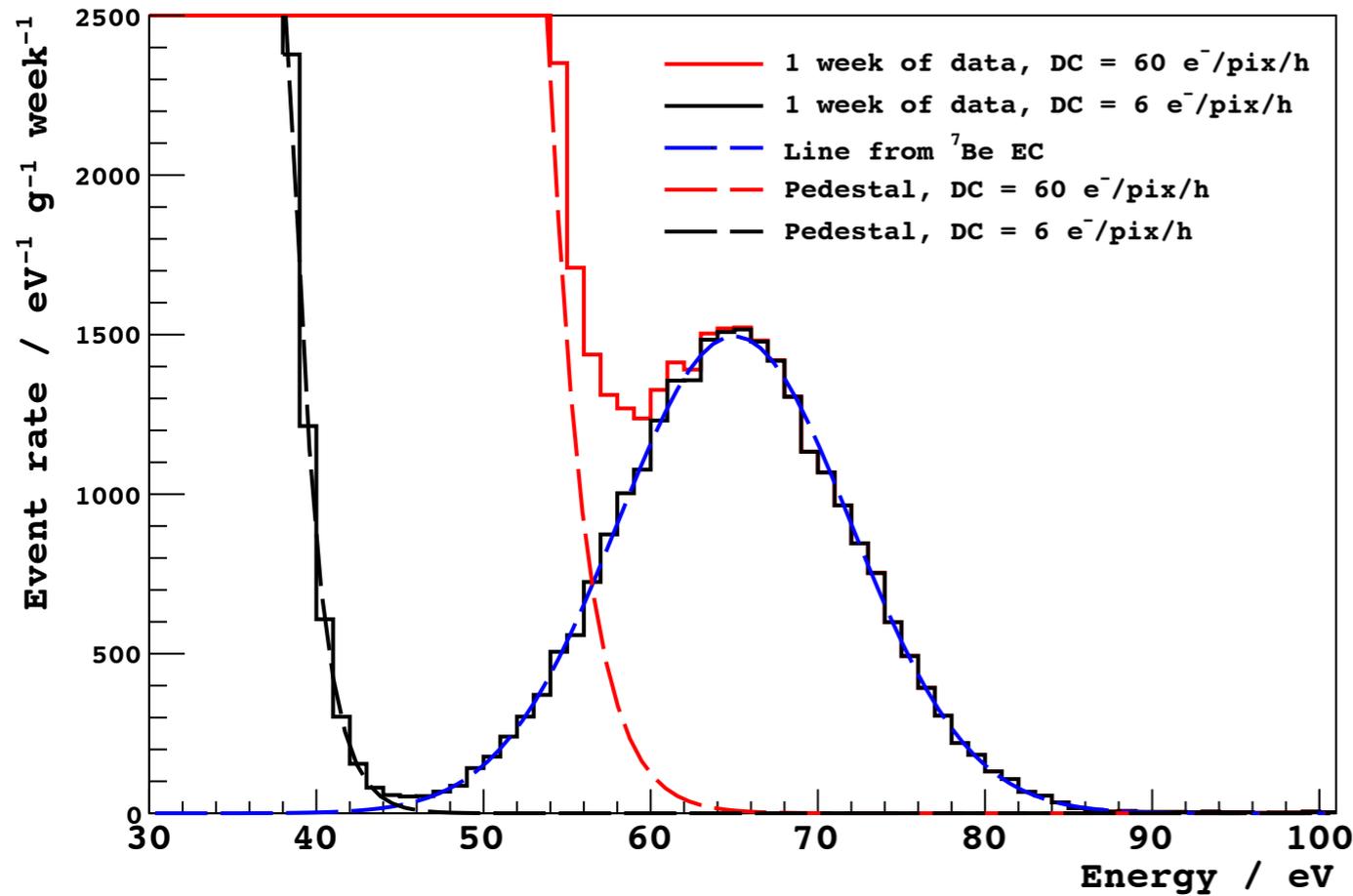
Activation  
of a  
fraction of  
a Bq  
( ${}^7\text{Be}$  and  
 ${}^{22}\text{Na}$ )

$\gamma$ -ray may  
be used  
to  
precisely  
measure  
activation

K-shell  
line near  
threshold

Shift in line  
due to  $A$   
recoil

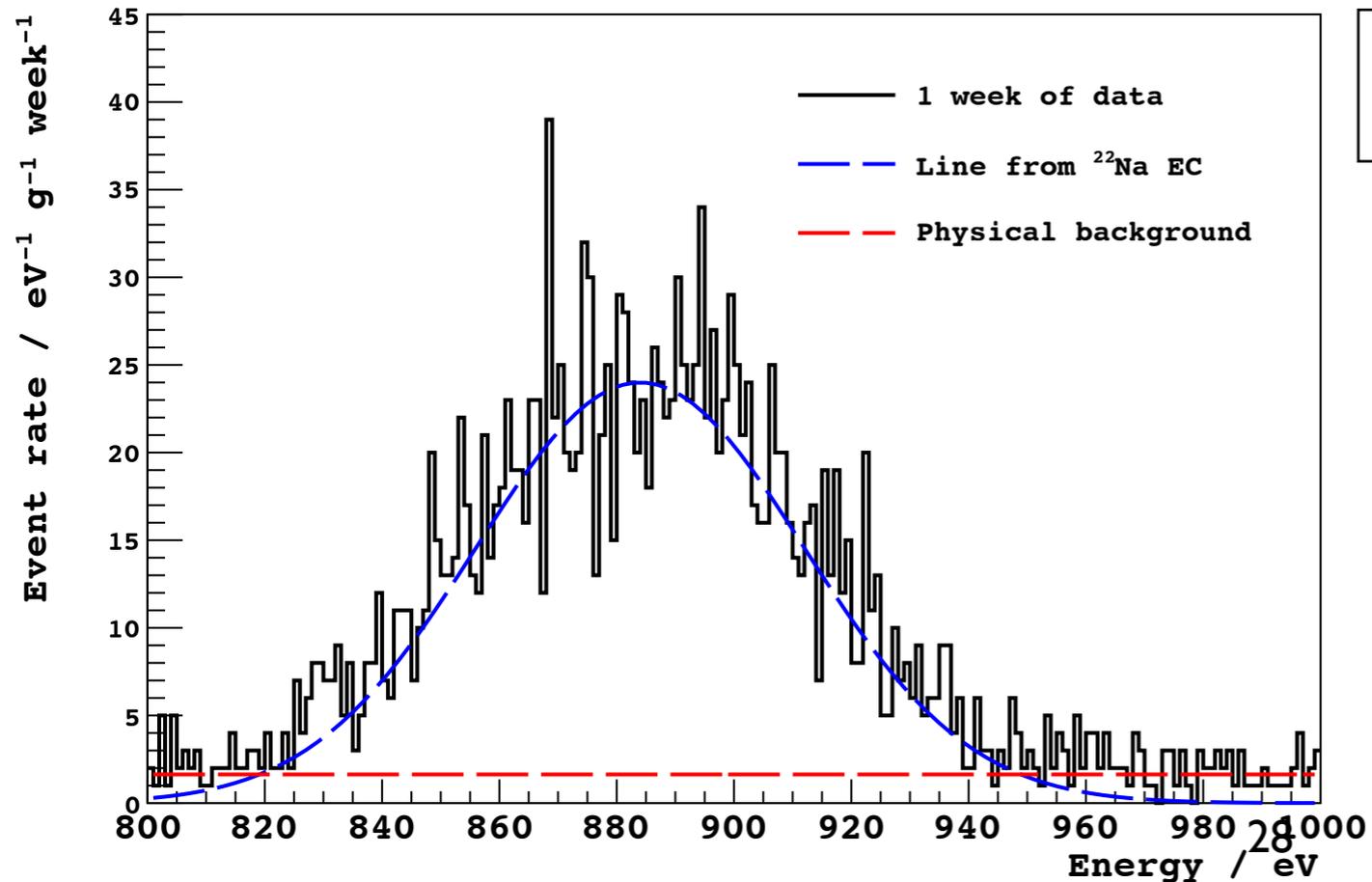
CCD spectrum 60 days after  $10^{10}$  protons  $\text{cm}^{-2}$  exposure



${}^7\text{Be}$  EC

Threshold need to be as low as good CCD

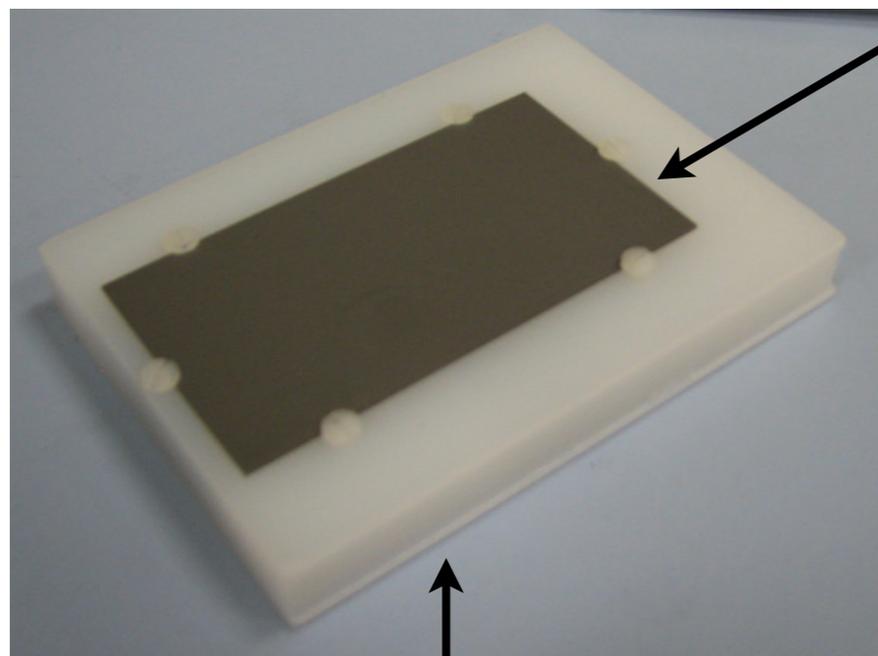
CCD spectrum after  $10^{10}$  protons  $\text{cm}^{-2}$  exposure



${}^{22}\text{Na}$  EC

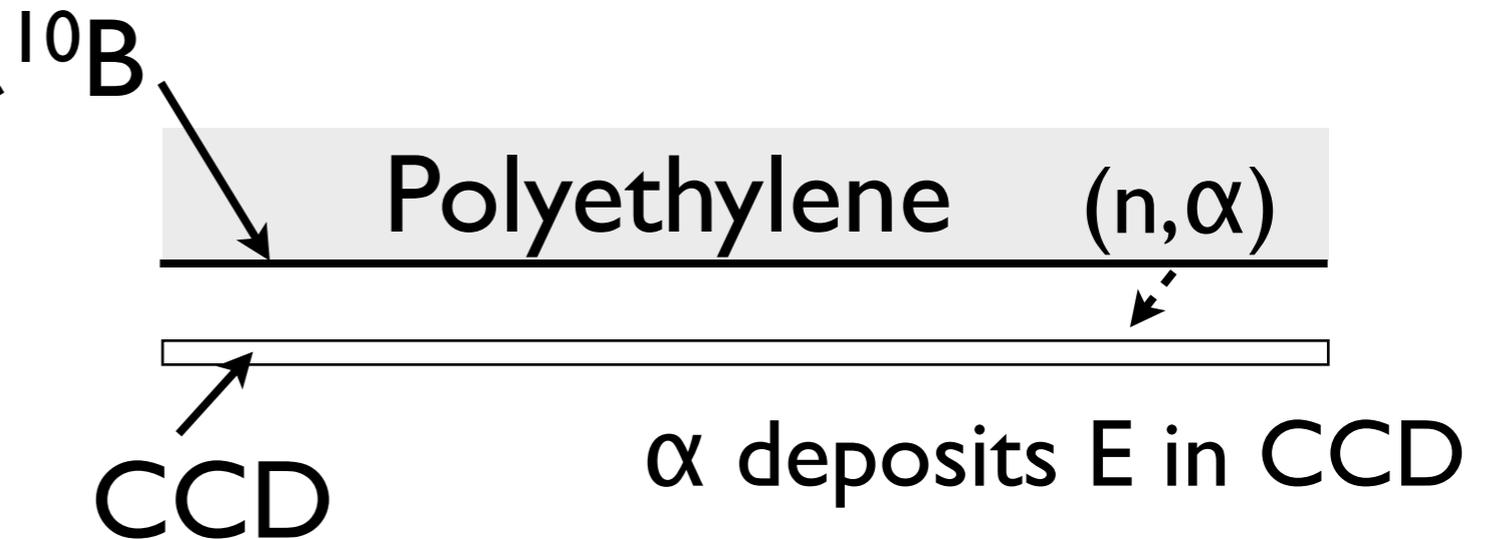
“Easy”  
Physical background from DAMIC surface run

# In-situ neutron background estimate

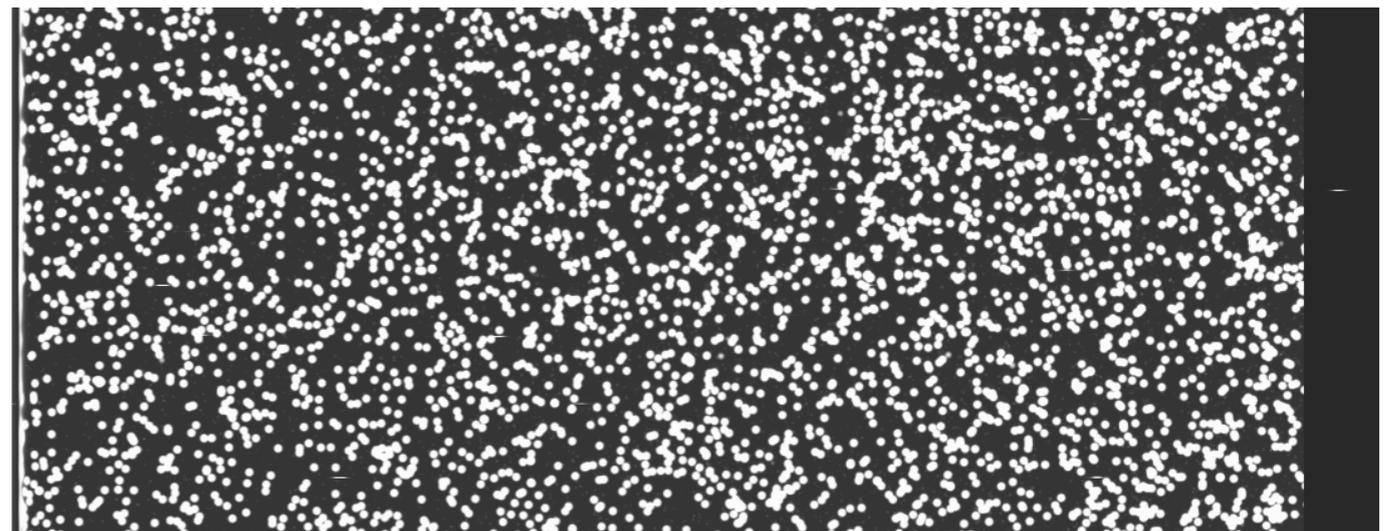


Slides into Cu box at SNOLAB

Test performed at FNAL this summer



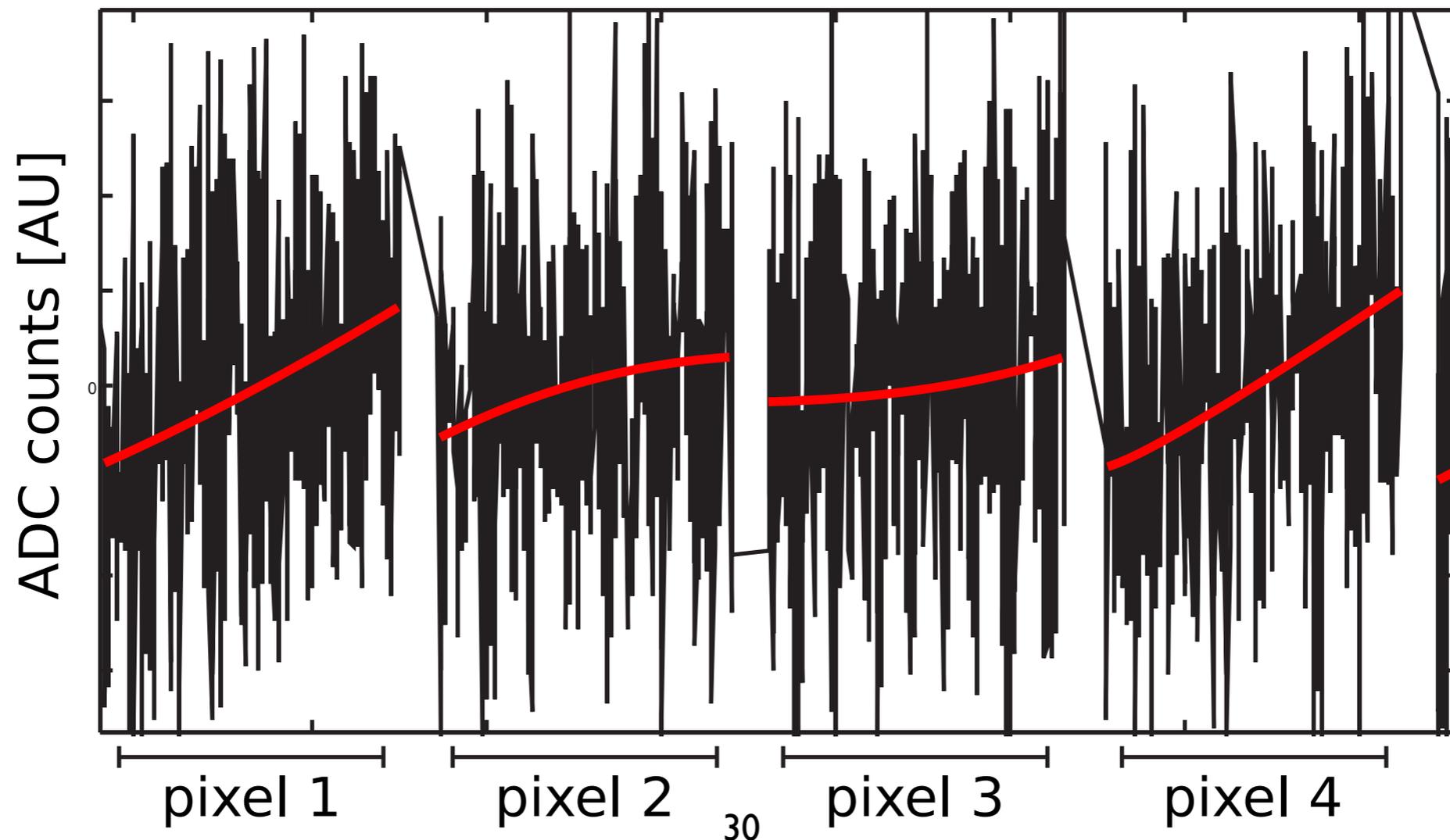
$\alpha$ s from  $^{241}\text{Am}$  source



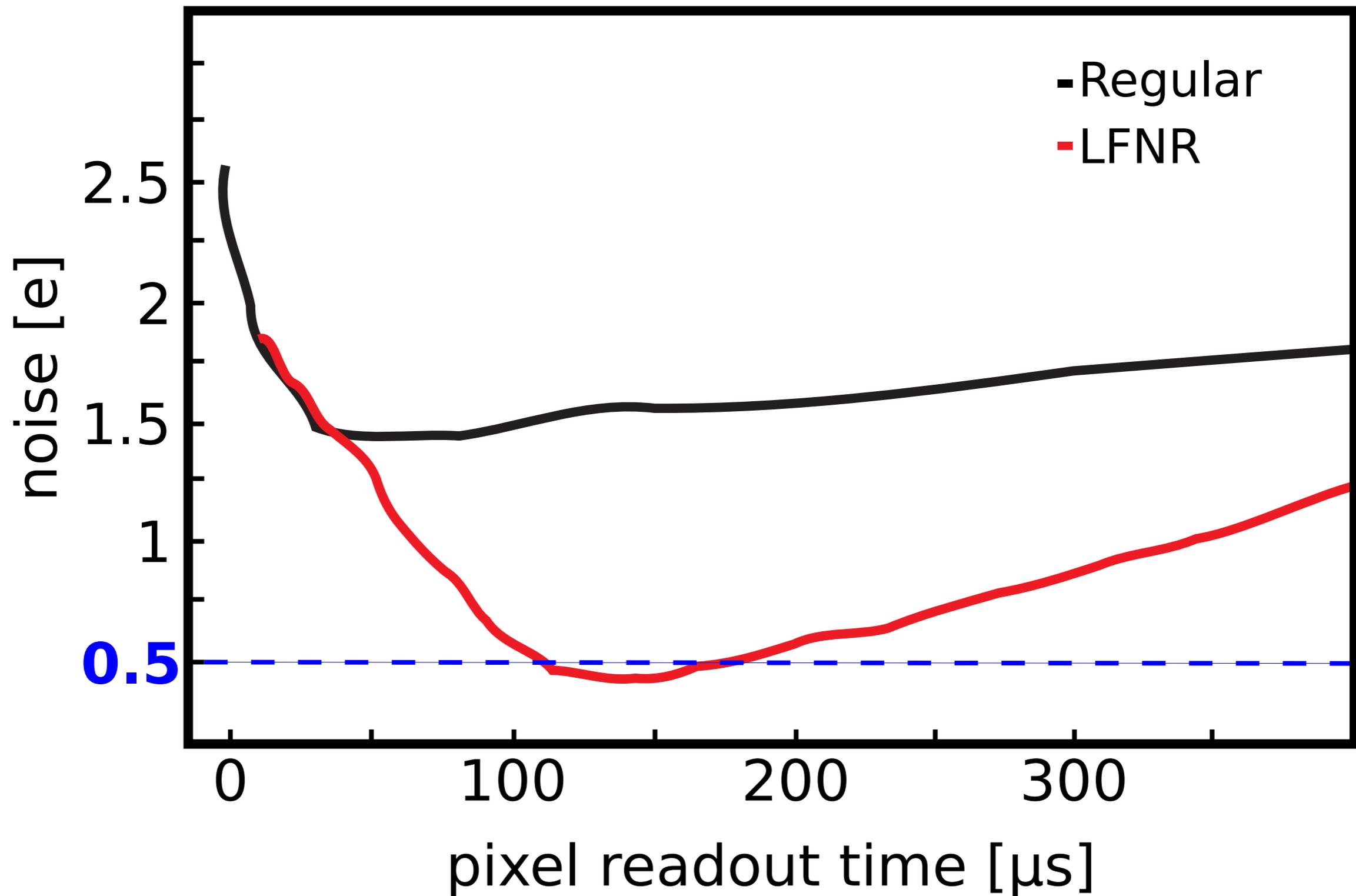
Nucl.Instrum.Meth. A665 (2011) 90-93

# Lowering the noise: Low Frequency Noise Reduction

- There is some low frequency tendency that has a significant effect in the pixel error.
- This slow variation are estimated for each pixel using Least Square Fitting.



# Lowering the noise: Low Frequency Noise Reduction



# Lowering the noise: Skipper CCD

- Main difference: the CCD allows multiple sampling of the same pixel without corrupting the charge packet.

- The final pixel value is the average of the samples

$$\text{Pixel value} = \frac{1}{N} \sum_i^N (\text{pixel sample})_i$$

